HYDROGEOMORPHIC EVALUATION OF ECOSYSTEM RESTORATION AND MANAGEMENT OPTIONS FOR CAPE ROMAIN NATIONAL WILDLIFE REFUGE

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EXECUTIVE SUMMARY

This report provides a hydrogeomorphic (HGM) evaluation of ecosystem restoration and management options for Cape Romain National Wildlife Refuge (CRNWR) including the recent boundary expansion encompassing Jeremy Island and the mainland White and King tracts. CRNWR encompasses 66,287 acres and spans 22 miles of the South Carolina coast, and it protects critically important estuarine and island habitats used by diverse animal communities including many species of concern birds, turtles, marine fisheries and shellfish, and mammals. CRNWR contains 29,000 acres of Class I Wilderness Area and is recognized as one of only five NWRs included in the UNESCO Biosphere Reserve Program. Despite its exceptional resources, the refuge has been influenced by many on-and off-site developments that have degraded or reduced valuable habitats such as the diversion and reduction of freshwater and sediment inputs to the regional coast, bays, and islands; construction of the Atlantic Intracoastal Waterway (AIWW); coastal and bay development and contamination; and sea level rise. Objectives of this HGM report are:

1. Describe the pre-European settlement ecosystem condition and ecological processes in the CRNWR region.
2. Document changes in the CRNWR ecosystem from the pre-settlement period with specific reference to alterations in hydrology, vegetation community structure and distribution, and resource availability to key fish and wildlife species.
3. Identify restoration and management options incorporating ecological attributes needed to restore specific habitats and conditions within CRNWR.

Information for this study was obtained on historical and contemporary geology and geomorphology, soils, topography, climate and hydrology, and plant and animal communities in the CRNWR region. The Atlantic Coastal Plain (ACP) of South Carolina was created by periods of glaciation, uplift and subsidence, and associated sea level changes since the Upper Cretaceous Period. The sea level of the ACP rose and fell multiple times over the past million years and caused the coastal shoreline to migrate across the coastal plain of South Carolina. As sea levels rose and fell, barrier island systems developed up to the Piedmont Province in South Carolina, creating progradation beach ridge systems and seven sequential coastal terraces. The Pamlico Terrace is the lowest elevation terrace existing at 25 feet above mean sea level and it incorporates the CRNWR region. This region lies in a microtidal, mixed-energy, coastal zone that created prograding and retrograding barrier island systems. Processes creating prograding and retrograding shorelines historically occurred on various barrier islands depending on sediment sources, wave action, inlets, and geological characteristics. Bulls and Cape islands are prominent features of the refuge, which were historically sustained by longshore drift and sediment deposition entering the region primarily from the inland Santee River Delta. Many other small rivers and creeks entered Bulls Bay and tidal action created a wide variety of landform features such as ebb tidal deltas, swash bars, terminal lobes, flood channels, and linear bars.

Most of CRNWR is covered by four major soil associations that contain 10 distinct soil types. The types and distribution of soils reflect varied periods of sediment deposition during coastal submersion. Tidal Marsh, Soft soils cover the majority of the refuge except Cape and Bulls islands and mainland areas. These soils are inundated by high tides and are saturated the rest of the time. Capers soils occur on Bulls and Cape islands and few other locations in the northeastern part of the refuge and reflect a higher elevation tidal marsh environment such as tidal flats. Barrier island soils are more recent depositions during the Holocene Period. The Crevasse-Dawhoo soil complex occurs on Bulls Island, with Crevasse soils on ridges and Dawhoo soils in swales or troughs. Meggett, Rutlege, Seewee, Lakeland, Chipley, and Cape Fear soils are present on mainland area, including the White and King tracts. Coastal beaches and dune land soils contain fine sands that typically are flooded by tides twice daily.

Topography of CRNWR reflects varied island, bay, estuarine, and mainland surfaces along with the myriad creeks and tide channels. Light Detection and Ranging (LiDAR) surveys have been completed for northern Charleston County and CRNWR, but currently processed LiDAR data are only available for two-foot contour intervals.

The climate of CRNWR is characterized by humid and subtropical conditions with mild winters and hot humid summers. About 15% of annual precipitation for the region is from major tropical storms and average rainfall is from 46 to 55 inches. As an example, the Category 4 Hurricane Hugo greatly impacted the refuge in 1989. Recently, a Water Resources Inventory Assessment (WRIA) was conducted for CRNWR, which summarizes local and regional climate dynamics and hydrology. The hydrological regime of the region is complex with fresh and seawater inputs derived from both surface and groundwater interactions. The refuge lies adjacent to the outlet of the large Santee River Basin. Many mainland creeks provide freshwater inputs to CRNWR and brackish creeks associated with the ebb and flow of tides also influence bay and marsh water movements and ecology. Tides at the refuge are semi-diurnal comprised of two high and two low tides each lunar day. The tidal range at CRNWR is 1.6m for neap tides and 1.9m for spring tides, with the average significant wave height of 1.3m.

Historically, CRNWR contained a variety of habitat types including tidal creeks and flats, emergent estuarine marsh, sand beaches and dunes, maritime forest, a small area of mainland upland forest, and small freshwater wetland depressions. Recognizing the historical coastline dynamics of the refuge, we prepared an HGM matrix of relationships of major vegetation communities in the region to geomorphic surface, soil, topography, and hydrological regimes. This matrix then enabled the development of a potential natural vegetation distribution map specifically for CRNWR. This map essentially predicts the distribution of communities that are similar to those that would have occurred during period of the late-1800s to early-1900s. In general, the combination of coastal island and shoreline geomorphology, soils, and elevation was the best predictor of historical vegetation community distribution on the refuge and reflects the divergent hydrology of the coastal surfaces and locations. The dominant communities of emergent estuarine marsh, beaches and dunes, and maritime forest at the refuge occupy distinct HGM settings that reflect coastal hydrology and morphology that grades from the ocean and bays to higher elevation mainland (or island) areas.

Animal communities at CRNWR are diverse and occupy the many ecological niches provided in freshwater and brackish-coastal habitats. These species include numerous water and seabirds, landbirds, mammals, amphibians and reptiles, mollusks, and fish. Several threatened and endangered species regularly use resources and habitats on the refuge, such as the southeastern loggerhead sea turtle (*Caretta caretta*), where Cape Island supports the largest nesting population of the species north of Cape Canaveral, Florida

The historical and more contemporary changes to the CRNWR region, and specific refuge lands, are chronicled in this report including discussion of early settlement and land use changes, contemporary hydrologic and vegetation community changes, and refuge development and past management. The primary ecosystem changes that need to be addressed for future restoration and management goals of CRNWR are: 1) alterations to the local and regional distribution, chronology, and abundance of fresh and salt surface water; 2) changes in sediment load, quality, and distribution in coastal rivers and bays and offshore transgressive deposition of sediment in estuarine marshes and on islands; 3) increased rate and extent of erosion on barrier islands; 4) development and maintenance of the AIWW; 5) increased continental and regional temperatures and accelerated sea level rise; and 6) invasion of exotic plants on barrier islands and mainland tracts.

Fortunately, much of the historical Cape Romain NWR community type and distribution remain mostly intact and a primary goal for the future of the refuge is to protect the ecosystem character and its driving ecological processes where possible. Most of the landscape issues that affect the long-term character of the refuge are off-site and reflect large systemic land, water, climate, and sea level rise changes. As such, this HGM report reaffirms the need to understand the potential effects of these larger issues and encourage the U.S. Fish and Wildlife Service (USFWS) to participate in, and develop strategies for, conservation efforts and programs to address and mediate the potential changes. Managers should pay close attention to several impending future ecosystem changes, some of which are far beyond the scope of USFWS control and the ability of this report to make suggestions about changes (e.g., climate change and sea level rise). At a more local on-site refuge level, ultimately, management of natural vegetation community types and their inherent resources will require changes that help restore (to the extent possible) natural disturbance regimes, the hydrological flow pattern, timing and distribution of water management, and invasive plant management. Despite the probability of future ecosystem changes, CRNWR can continue to provide key resources to meet annual life cycle requirements for many plants and animals in the South Atlantic coastal region along with providing opportunities for consumptive and non-consumptive wildlife-dependent uses.

Two general ecosystem restoration “action” categories or “goals” that seem important to address the many existing and planned local/regional planning efforts and conservation/land use programs for CRNWR include:

1. Maintain and restore the physical and hydrological character of the regional South Atlantic coastal ecosystem.
2. Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes where possible and encourage management strategies that can emulate natural disturbance event processes and frequency including fire, flooding and drought, and wind/wave action and that can provide critical resources to key fish and wildlife species.

Specific recommendations to support the above restoration and management goals are provided in the report. For #1, recommendations include:

- Work to expand the acquisition boundary of CRNWR.
- Develop long-term strategic plans to protect and replace tidal marsh, tidal flat, and inland wetlands under scenarios of up to 2m sea level rise over the next 100 years.

- Cooperate with the Santee Cooper Power Company and state partners to ensure adequate freshwater and sediment inflows to coastal bays, marshes, and barrier islands.
- Continue to work with the U.S. Army Corps of Engineers to increase the amount of sand that is transported down the coastline and that could potentially become deposited on barrier islands.
- Cooperate with other agencies to prevent, remove and mitigate hazardous waste materials, oil spills, and degraded water quality in the region.
- Ensure that maintenance and new construction on the AIWW does not cause increased coastline erosion, disturbance to critical habitats and resources, degrading dredge material locations, contamination, and deposition of material containing seedbanks of invasive plant species.
- Work with partner agencies and groups to monitor and develop strategies for protection, and possible rebuilding, of the barrier island shorelines from excessive erosion, loss of accretion, storm and wave effects, and sea level rise.

Specific recommendations for #2 include multiple actions for each major community/habitat type. A brief synopsis of these recommendations for each habitat is to:

- Protect existing beach and sand dune/spit areas by controlling access, maintain Class I Wilderness Area protection status and management, minimize disturbance, remove and control invasive plant and animal species, restore native plant communities, conduct necessary cleanup activities, and evaluation of potential methods to protect islands and beach/dune areas from further erosion and to rebuild them if possible.
- Protect existing maritime forest habitat from conversion to other uses, excluding fire except in very special cases, control invasive plants and remove Chinese tallow from Bulls Island, and conduct long-term monitoring of maritime forest on Bulls Island.

- Protect existing upland forest by restricting further development and fragmentation, acquire upland pine forest habitat to connect CRNWR with the Francis Marion National Forest, restore longleaf pine in appropriate areas, and manage upland forest with prescribed fire, harvest and timber stand improvement, and cooperation with Francis Marion National Forest timber management plans.

- Protect existing tidal flats, shell rakes, oyster bars, and emergent marshes from fragmentation, erosion, contamination and unnatural disturbance; evaluate mainland or coastal edge sites that could be restored to estuarine marsh and tidal flat habitats to mitigate for loss from future sea level rise; establish vegetation monitoring locations to determine short-and long-term changes; prevent and control hazardous waste and oil spills to the degree possible; refine projections of changes in marsh and flat area an d headwater incision of tidal creeks under various sea level rise scenarios; evaluate current oyster beds and shell rakes; evaluate use of water buffer zones to minimize disturbance to nesting birds; and evaluate the placement of shell barriers in bay areas adjacent to tidal marshes to reduce wind/wave action and erosion of marsh/flat sediments.

- Protect the physical and hydrological integrity of small wetland depressions; maintain existing water-control infrastructure on Bulls Island where desired, but manage the infrastructure for natural ebb-and-flow of tidal entry and exit; evaluate ways to maintain at least some fresh to brackish wetland habitat on Bulls Island; in the long-term restore artificial wetland impoundments on Bulls Island to tidally influenced emergent esturarine marsh given future sea level rise scenarios; protect and restore freshwater wetlands in forest swale locations along the coastal mainland; control woody vegetation expansion into freshwater wetlands; and prevent future introduction an establishment of non-native species in freshwater wetlands.

The current understanding of the CRNWR ecosystem has been greatly enhanced by documentation of system attributes and management actions (such as in the past refuge annual narrative reports), monitoring of coastline erosion, evaluation of the success of certain management activities (such as control of Chinese tallow), and species-specific studies of vegetation and animals. Future management of the refuge should continue to incorporate key monitoring studies and direct research as needed. Ultimately, the success in sustaining communities and ecosystem functions will depend on how well the physical integrity and hydrological processes within the refuge can be protected, restored, and emulated by management actions relative to sea level rise and the loss of coastal barrier island habitats. Coastal processes need to be evaluated at the appropriate spatial and temporal scales. Therefore, monitoring and evaluation of the management strategies employed at CRNWR must be conducted long enough to account for the spatial and temporal rate of change for the different abiotic and biotic characteristics that are altered. Specific information and monitoring needs for CRNWR related to HGM information and also identified in the refuge WRIA include:

- Obtain complete LiDAR topography data at a refined elevation scale for the refuge.
- Evaluate methods and efficacy of controlling invasive species.
- Conduct long-term monitoring of water quality, tide and bay regimes, and sea level rise.
- Evaluate and monitor long-term changes in vegetation and animal communities.
- Conduct detailed mapping of refuge vegetation.
- Document changes in wetland and upland habitats as hydrological regimes change.
- Monitor key animal species.
- Evaluate the use of fire in select habitats to control invasive species and promote restoration of native vegetation cover and diversity.

INTRODUCTION

Cape Romain National Wildlife Refuge (NWR) was established in 1932 under the Migratory Bird Conservation Act "for use as an inviolate sanctuary, or for any other management purpose, for migratory birds" (16 U.S.C.§ 715d Migratory Bird Conservation Act; USFWS 2010). With its establishment, Cape Romain NWR became one of the first refuges created to protect important estuarine and island habitats along the southern Atlantic Coast. In 1936, Cape Romain NWR was significantly expanded when Gayer Dominick conveyed the 5,129-acre Bulls Island to the U.S. Fish and Wildlife Service (USFWS) for inclusion in the refuge. Minor boundary expansions have added Jeremy Island (1,018 acres), and identified mainland tracts (the White and King tracts containing 1,658 acres) to eventually expand refuge lands and facilitate a common boundary with Francis Marion National Forest.

Today, Cape Romain NWR encompasses approximately 66,287 acres and spans 22 miles of the South Carolina coast (Figs. 1, 2). Of those acres, about 35,267 acres are terrestrial, consisting of sandy beaches and dunes, tidal marsh, maritime forest, natural wetlands, and fresh and brackish water impoundments. An additional 31,000 acres consists of open water and tidal creeks, constituting the majority of waters under lease with the State of South Carolina.

In 1975, 29,000 acres encompassing marsh and barrier island habitat (with the exception of Bulls Island and a small strip along the Atlantic Intracoastal Waterway (AIWW) was designated as the Cape Romain Class I Wilderness Area (Fig. 2) by Public Law 93-632. Class I Federal Wilderness lands, (wilderness areas larger than 500 acres that were in existence in 1977), are preserved as part of the National Wilderness Preservation

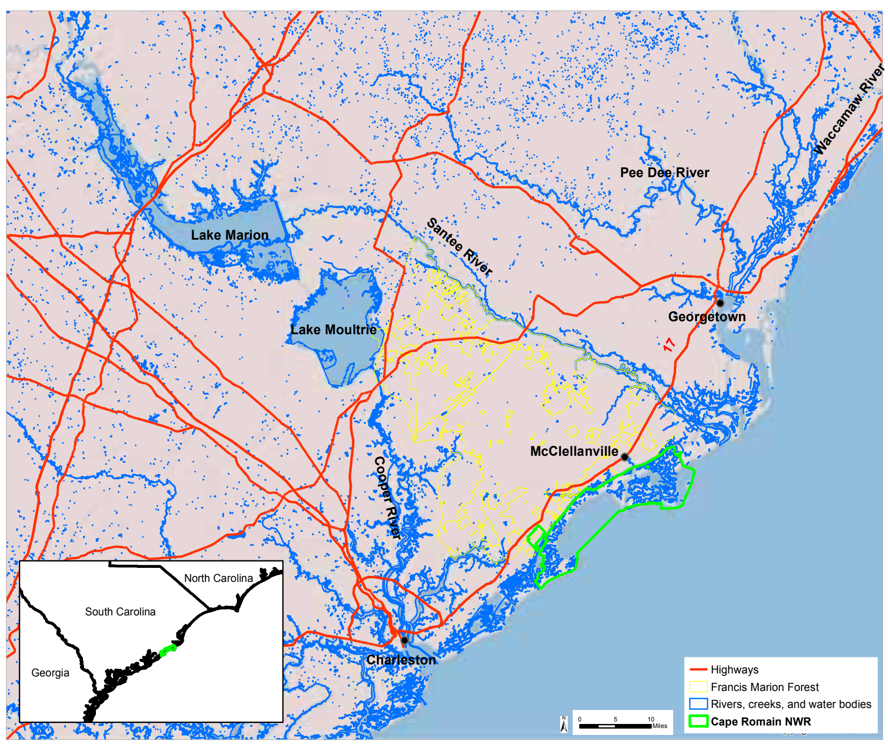


Figure 1. General location of Cape Romain National Wildlife Refuge and dams/reservoirs on the Santee and Cooper rivers, South Carolina. Refuge boundary depicts the current acquisition boundary as of April 2014.

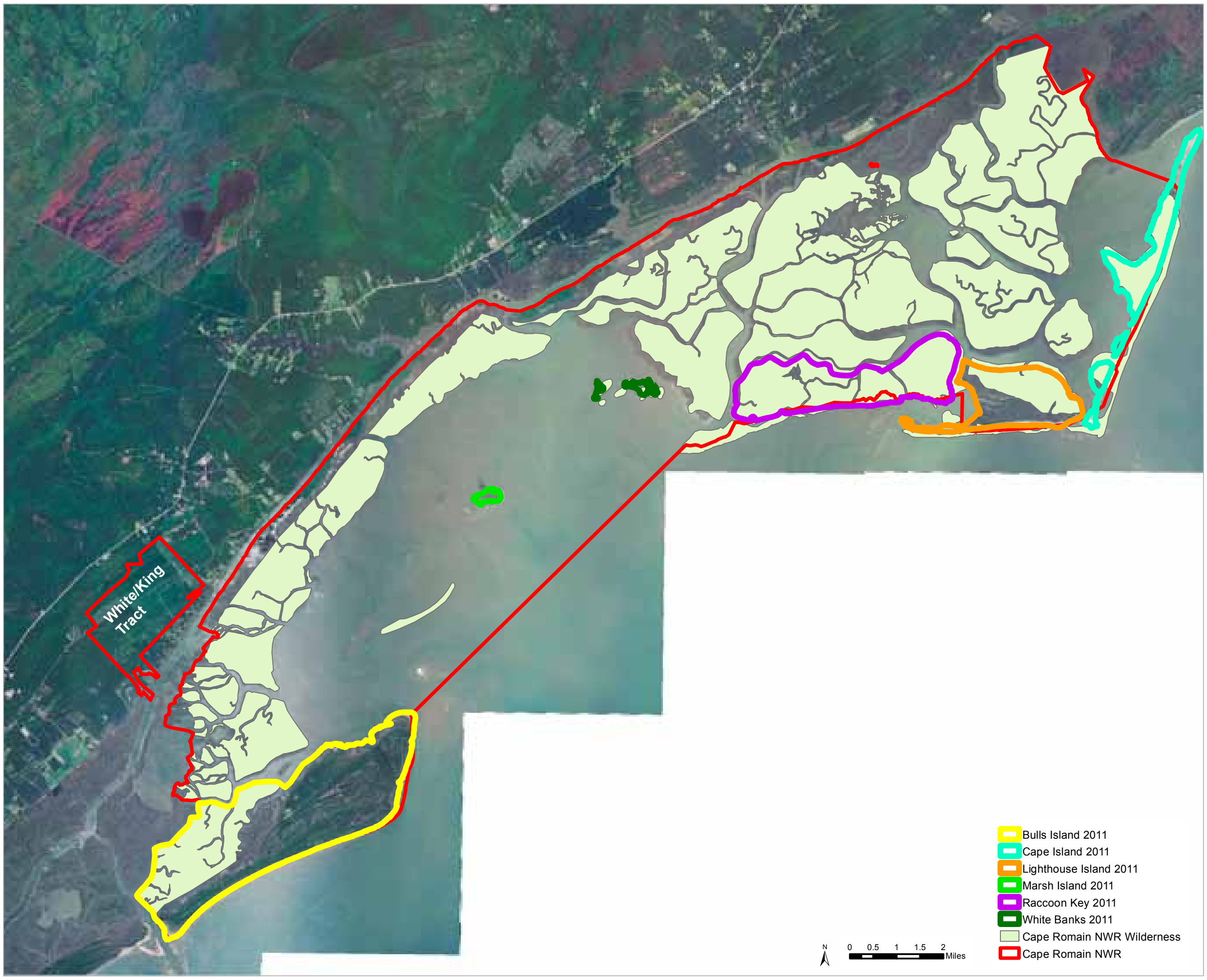


Figure 2. Location of barrier islands and the designated Class I Wilderness Area on Cape Romain National Wildlife Refuge.

System under the Wilderness Act (1964), and afforded special protection under the Clean Air Act. Mandatory Class I Federal lands include all national wilderness areas exceeding 500 acres. Such lands may not be redesignated (42 U.S.C. 7472). Additionally, national wildlife refuges which exceed 10,000 acres may only be redesignated by States as Class I or Class II areas (42 U.S.C. 7474). In addition to the prohibitions of motorized and mechanized vehicles, timber harvest, grazing or mining activity, or any kind of development in Wilderness areas, Class I Wilderness areas have rigorous air quality standards and monitoring requirements (e.g. restrictions for particulate matter and sulfur dioxide see http://fws.gov/laws/lawsdigest/CLENAIR.html). Three research natural areas have also been established in the refuge, and the refuge is recognized as one of only five NWRs included in the United Nations Educational Scientific and Cultural Organization (UNESCO) Biosphere Reserve Program as the Carolinian-South Atlantic Biosphere Reserve.

The refuge's establishing purposes for migratory birds have not changed, however additional responsibilities have been added to include protection of threatened and endangered species, preserving the Class I Wilderness area, and maintaining maritime forest habitats on Cape and Bulls Islands (USFWS 2010).

Many important on- and off-site developments have influenced Cape Romain NWR since well before its establishment (see for example Faustini et al. 2013:20-25). A Civilian Conservation Corps (CCC) camp was established on Bulls Island in 1938, and the CCC constructed Jack's Creek Dike that created the Jacks Creek wetland impoundment (USFWS 2010). At the same time, the Works Progress Administration (WPA) stationed on Lighthouse Island constructed a ¾ mile long dike on Cape Island to create a 300-acre freshwater impoundment for waterfowl management. In 1939, construction of the large Santee River Dam was initiated on the Santee River as part of the WPA to provide hydroelectric power to the state of South Carolina. The eight mile long dam was completed in 1941 and is approximately 80 miles upstream from where the Santee River empties into the Atlantic Ocean north of Cape Romain NWR. The WPA projects created two reservoirs - Lake Marion covering 110,600 acres on the Santee River, and Lake Moultrie on the Cooper River covering 60,400 acres (Fig. 1). Water developments also diverted surface water from the Santee River to the Cooper River, which relocated freshwater and sediment inputs to the coast south of Cape Romain NWR. These water diversions and managed releases on Lake Marion and Lake Moultrie significantly altered the historical Bulls Bay and associated salt marsh and barrier island ecosystem on the refuge (Hughes 1994, River Restoration Case Study). In addition to major hydrological effects of the Santee Dam on the Cape Romain NWR system, the AIWW was completed through the refuge in 1947. The AIWW generally followed natural waterways within the Cape Romain NWR although it has since been deepened and widened with some dredging activities occurring along the refuge perimeter over time.

Since its establishment, Cape Romain NWR management strategies have focused on the protection of bay and tidal marsh habitats, creating and maintaining freshwater impoundments for waterfowl on Bulls Island, recovering threatened loggerhead sea turtles (Caretta caretta), maintaining habitat resources for several threatened and endangered species, and preserving a Class I Wilderness Area, among others (USFWS 2010). Cape Romain NWR currently is designated as critical habitat for the Endangered piping plover (Charadrius melodus) and is soon to be designated critical habitat for the red knot (Calidris canutus) that is proposed for Threatened status. The refuge is a critical resource for many shorebird species and is recognized as a Western Hemisphere Shorebird Reserve Network Site of international importance, a designation that is limited to those areas that support at least 100,000 shorebirds annually or at least 10% of the biogeographic population for a species. Several shorebird species breed and nest on the refuge; many shorebird species utilize the refuge's impoundments, tidal marsh, islands, beaches and shoreline including red knot, piping plover, black-necked stilt (*Himantopus mexicanus*), whimbrel (*Numenius phaeopus*), and American oystercatcher (*Haematopus palliates*) (USFWS 2010).

Beach and shoreline habitats within the refuge are designated as critical habitat for loggerhead sea turtles and support the largest nesting population north of Florida (http://www.fws.gov/northflorida/SeaTurtles/2014_Loggerhead_CH/Terrestrial_critical_habitat_loggerhead.html). Coastal estuarine marsh habitats also support many species of concern (USFWS 2010) and protecting water quality in the estuary is vital for critical ecological resources used by these species. Cape Romain NWR is within Shellfish Management Area 06B, an area where shellfish harvesting is restricted and is an area of concern from adverse water quality (Freeland 2012).

Perhaps the most challenging long-term ecosystem change at Cape Romain NWR is ongoing and forecasted sea-level rise due to continental climate change, concurrent with marsh subsidence. Beach/dune and shoreline habitats have decreased on Cape Romain NWR over time, especially on the barrier islands due to erosion, sea level rise, and storms. Although the accuracy and predictive qualities of Sea Level Affecting Marshes Model (SLAMM) analyses are limited (Clough et al. 2010), SLAMM models suggest dramatic future changes for the barrier islands, estuary and freshwater wetlands, and other near-shore habitats at Cape Romain NWR (Warren Pinnacle Consulting 2012). In general, model forecasts indicate that barrier islands will continue to erode and shrink in size; estuary marshes will convert to more open water; interior freshwater wetlands will become connected to sea water or have increased salt water intrusion from more frequent storm events, high tides and storm surges; and maritime forest area will decline (e.g., Fish et al. 2005, Warren Pinnacle Consulting 2012). As an example of the effects of continued sea-level rise, the current Jacks Creek impoundment on Bulls Island has been and will continue to be threatened by encroaching high tides that have repeatedly damaged the exterior dike on the Atlantic Ocean side. Another compounding factor is the recent increase in non-native invasive plant species throughout the refuge where storms and high tides have degraded native maritime forest on barrier islands and inland coastal areas (USFWS 2010).

A Comprehensive Conservation Plan (CCP) was completed for Cape Romain NWR in 2010 to identify habitat and public use goals important for refuge management in the succeeding 15 years (USFWS 2010). In 2013, a Water Resource Inventory and Assessment (WRIA) report was completed for the refuge (Faustini et al. 2013), and a Habitat Management Plan (HMP) for the refuge currently is being developed. Refuge staff currently seek to implement CCP habitat management goals within recognition of the constraints of future water management on Bulls Island, erosion of it and other barrier islands, current and future sea level rise, altered freshwater and sediment inputs to regional coastal and bay areas, and threatened and endangered species habitat management concerns.

This report provides a hydrogeomorphic (HGM) evaluation of the Cape Romain NWR, including the recent boundary expansion encompassing Jeremy Island and the identified mainland tracts for future expansion (White and King tracts), in order to identify options for future ecosystem restoration and management and assist with implementation of the refuge CCP and HMP. The HGM evaluation provides data and information about historical communities and their ecological processes, along with general recommendations for ecosystem restoration and management on the refuge. Recently, HGM has been used to evaluate ecosystem restoration and management options on many NWR's throughout the U.S. (e.g. Heitmeyer and Aloia 2013, Heitmeyer et al. 2014). These HGM evaluations obtain and analyze historical and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrology, 5) aerial photographs and maps, 6) land cover and plant/animal communities, and 7) physical anthropogenic features of ecosystems (Heitmeyer 2007, Klimas et al. 2009, Theiling et al. 2012, Heitmeyer et al. 2013). This information provides a context to understand the physical and biological formation, features, and ecological processes of lands within a NWR and the surrounding region. This historical assessment provides a foundation, or baseline condition, to determine what changes have occurred in the abiotic and biotic attributes of the ecosystem and how these changes have affected ecosystem structure and function. Ultimately, this information helps define the capability of the area to provide key ecosystem functions and values and identifies options that can help to restore and sustain fundamental ecological processes and resources.

Objectives for this HGM evaluation of Cape Romain NWR are:

Describe the pre-European settlement (hereafter pre-settlement) ecosystem condition and ecological processes in the South Carolina coastal region where refuge lands are located.

Document changes in the Cape Romain NWR ecosystem from the pre-settlement period with specific reference to alterations in hydrology, vegetation community structure and distribution, and resource availability to key fish and wildlife species.

Identify restoration and management options incorporating ecological attributes needed to restore specific habitats and conditions within various locations on Cape Romain NWR.

Ben Sumrell

THE HISTORICAL
CAPE ROMAIN NWR ECOSYSTEM

GEOLOGY AND GEOMORPHOLOGY

The Atlantic Coastal Plain (ACP) of South Carolina, where Cape Romain NWR is located, was created by periods of glaciation, uplift and subsidence, and associated sea level changes since the Upper Cretaceous period. A geological summary of the origin of the Cape Romain landscape is provided in Faustini et al. (2013), with select summary points provided below. The ACP lies adjacent to the upland Piedmont Province at the coastal "fall line" but shares an underlying rock layer of granite, schist, and gneiss commonly thought of as the basement surface (Siple 1957, Campbell et al. 2011). Sedimentary rocks from the Upper Cretaceous overlie these rock layers and are mostly limestone and unconsolidated sand, clay, gravel, and marl. These rocks may protrude to the surface in parallel belts from southwest to northeast and are more than 3,500 feet in depth (Siple 1957). Eocene and Pliocene formations are comprised in total or primarily of marine shells. Pleistocene formations coincide with multiple terraces and shorelines created by the advance and retreat of the sea over time (Cooke 1936). The Cape Romain NWR area sits in a region of compressive tectonic stress between the axes of two major structural features, the Cape Fear Arch to the northeast and the Southeast Georgia Embayment to the southwest (Fig. 3). This area occupies a "hinge zone" that accommodates tectonic movement between these two features. While the regional pattern of upwarping and downwarping is complex, the area encompassing Bulls Bay and areas to the west and southwest have exhibited persistently downward tectonic motion or subsidence (Weems and Lewis 2002). The ACP contains the Coastal Plain and Continental shelf from

Figure 3. Physiographic provinces along the south Atlantic coast in relationship to geological attributes. Cape Romain is located within the Outer Coastal Plain physiographic province along the coast between Charleston and the Santee River (from Campbell et al. 2011).

the Piedmont Province to the submerged edge of the continent. This shelf thickens to the southeast and is comprised of Cretaceous, Tertiary, and Quaternary rocks of unlithified sediments interbedded with sedimentary rocks (Fig. 4, Weems and Lewis 2002, Cooke 1936). Quaternary rocks at Cape Romain NWR are underlain by Eocene formations consisting of limestone and Tertiary sands. The refuge is within the Lowcountry or Southern Coastal Plain Sea Islands/Coastal Marsh Ecoregion (Fig. 5).

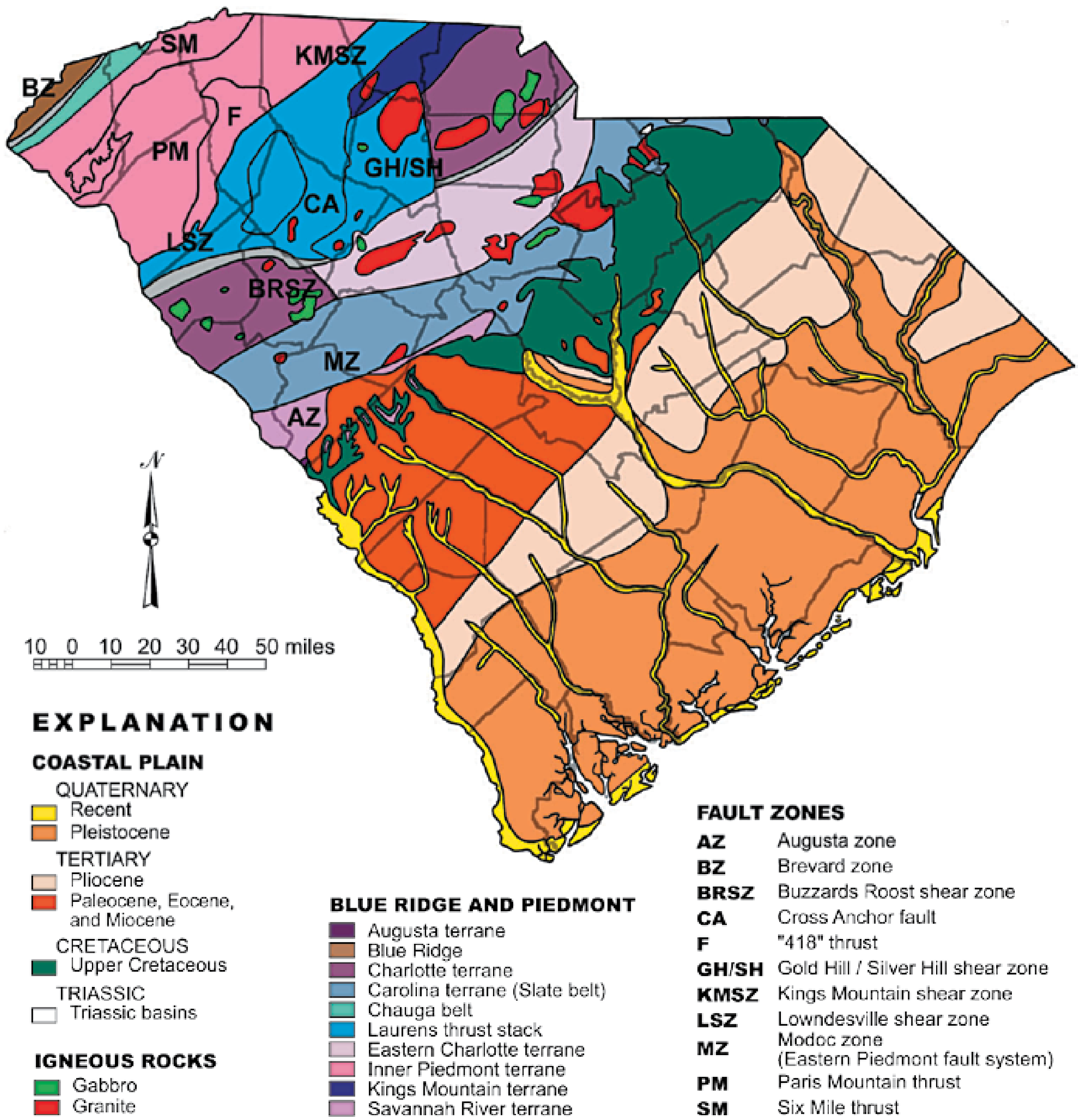


Figure 4. Geological map of South Carolina (from Harris et al. 2005). The Atlantic Coastal Plain contains the Coastal Plain and Continental Shelf from the Piedmont Province to the submerged edge of the Continent. This shelf thickens to the southeast and is comprised of Cretaceous, Tertiary, and Quaternary rocks of unlithified sediments interbedded with sedimentary rocks. Quaternary rocks at Cape Romain National Wildlife Refuge are underlain by Eocene formations consisting of limestone and Tertiary sands.

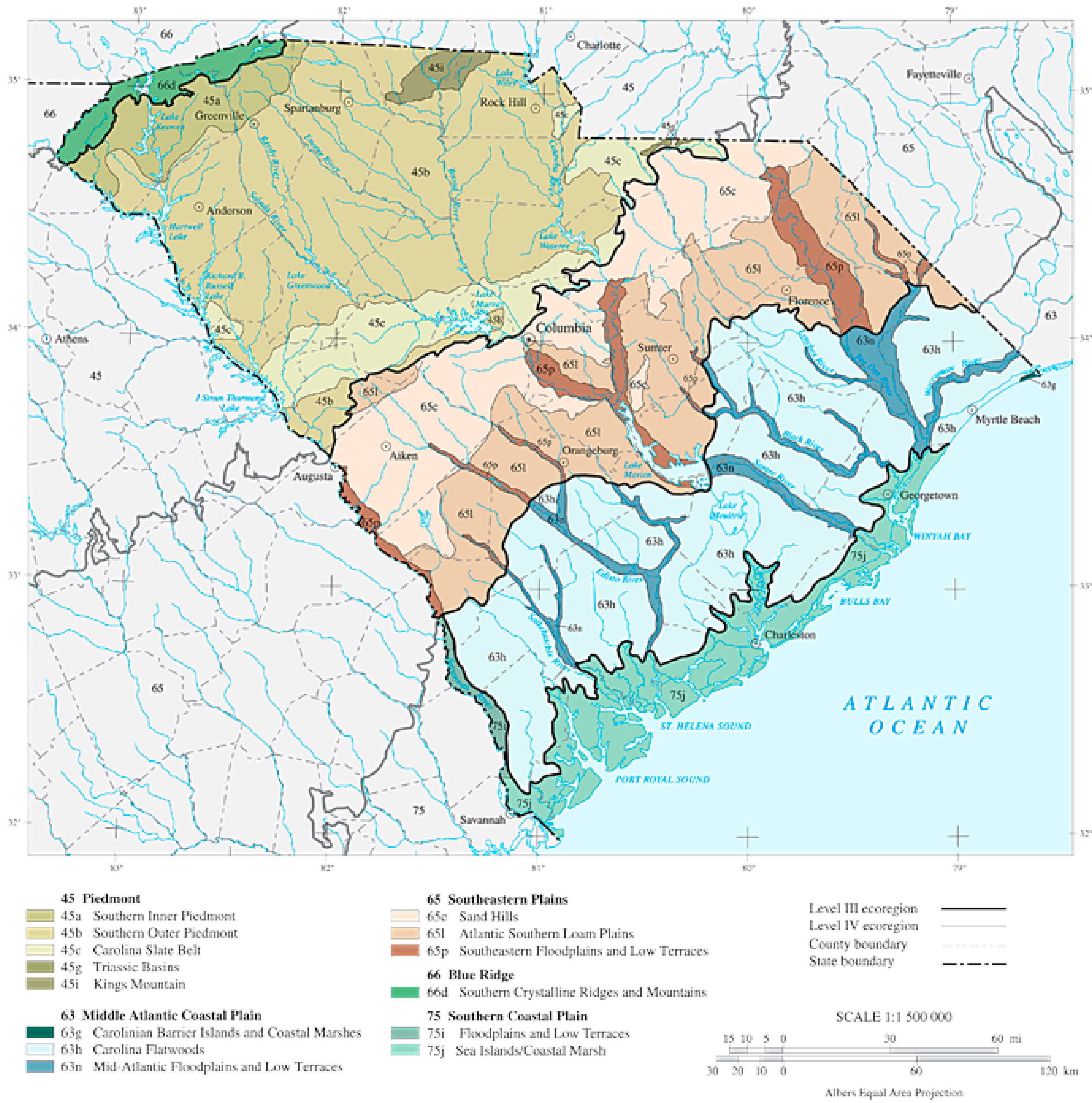


Figure 5. EPA Ecoregions of South Carolina. Cape Romain National Wildlife Refuge lies within the Sea Islands/Coastal Marsh ecoregion (from http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm).

The sea level of the ACP rose and fell multiple times over the past few million years (e.g. McKay et al. 2011). The dynamics of sea levels caused the coastal shoreline to migrate across the coastal plain of South Carolina and during glacial episodes sea level fell as much as 120 m. During interglacial periods, sea level rose to as high as 25 m above its present elevation from ice melt. This sea level rise and fall created a series of terraces that are separated by northeast-southwest trending erosional scarps and paleo-shoreline deposits that formed during sea level "highstands" (Barnhardt 2009).

As sea levels rose and fell, barrier island systems developed up to the Piedmont Province in South Carolina, creating progradation beach ridge systems dating to the Pleistocene that were only slightly modified throughout the Quaternary period (Harris et al. 2005). Seven coastal terraces have been documented associated with these changes in sea level rise. The Pamlico Terrace is the lowest elevation terrace existing at 25 feet above mean sea level (amsl) (Cooke 1936) and incorporates the Cape Romain NWR region. This region lies in a microtidal, mixed-energy, coastal zone creating prograding (also referred to as transgressive) and retrograding (regressive) barrier island systems (Harris et al. 2005). Processes creating prograding and retrograding shorelines historically occurred on various barrier islands depending on sediment sources, wave action, inlets, and geologic characteristics although the Cape Romain NWR region tends to be more transgressive in nature (Hayes and Michel 2008, Figs. 6a,b). Transportation of sediments at Cape Romain NWR occurs within five meters below mean low water. Long shore drift and bar welding causes the distinctive island drumstick pattern as winds move sands to the south, eroding the northern portions and creating a recurved spit in the southern portion of islands, while the central portion remains somewhat stable. The north or updrift end is commonly wider containing old vegetated dunes whereas the southern or downdrift end is narrower or hook shaped similar to Bulls Island (Fig. 7). Overall the Quaternary geologic characteristics of island morphology in this region (Fig. 4) are related to the "stratigraphic, geometric, and mechanical character of subsurface stratigraphic units and long-term evolution of the coastal regions" (Harris et al. 2005; Fig. 6).

River and creek channels originating in the uplands and draining the ACP have remained in fairly consistent locations over recent periods due to their formation between Holocene and Pleistocene barrier beach, which constricted their movement over time especially in relation to their inlet throats along the coast (Harris el al. 2005; Cooke 1936). Drainage of the coastal terraces is associated with younger materials (Cooke 1936). Tides and sediment transport from the Santee River Delta have caused accretion and erosion of the barrier island system depending on processes which influence various portions of the islands differently. As tides ebb and flow, wave action and sediment transport and deposition may create a wide variety of features such as ebb tidal deltas (Price Inlet) including ebb channels, swash bars, terminal lobes, flood channels, and linear bars. The number and width of inlets throughout this area are also a determining factor in processes such as inlet sediment bypassing which helps develop bar complexes based on sand transport mechanisms (Fitzgerald 1982).

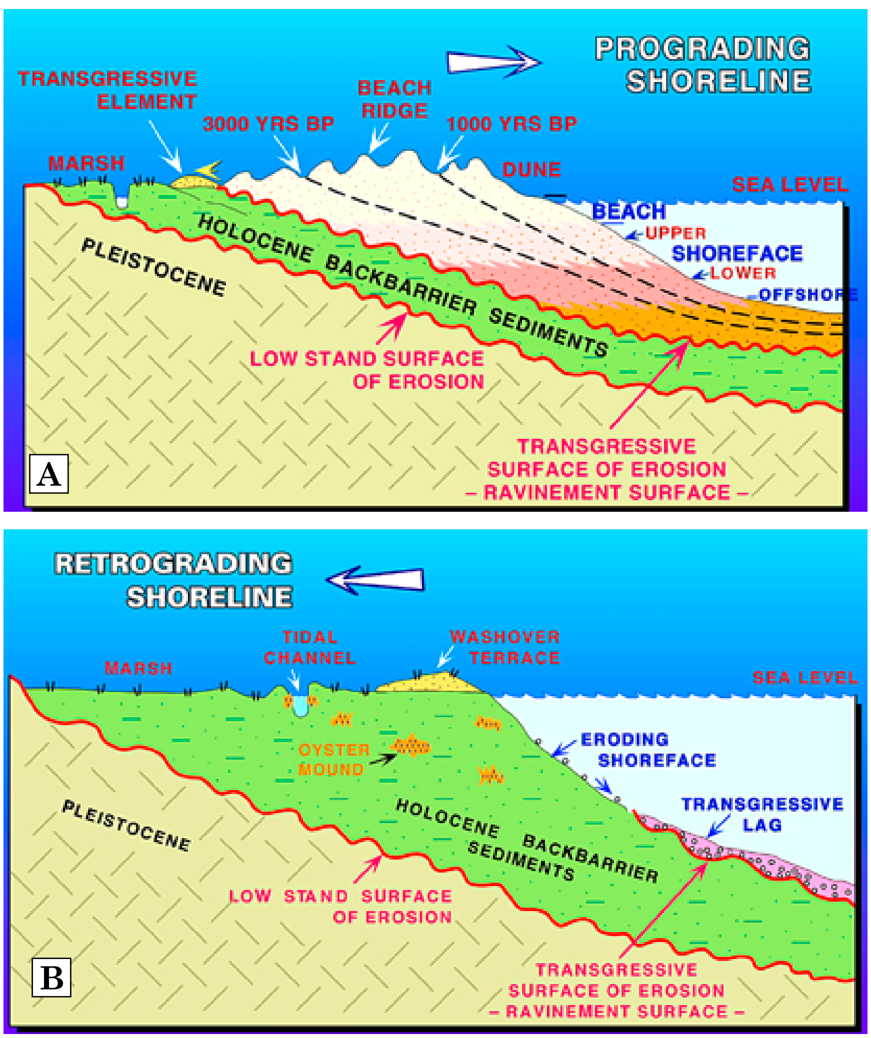


Figure 6. Cross section of barrier island geology and processes associated with: a) prograding island formation and b) retrograding island formation (from slide presentation of M.O. Hayes, Cape Romain National Wildlife Refuge files).

SOILS

Most of Cape Romain NWR is covered by four major soil type associations that contain 10 distinct soil types (Fig. 8). The types and distribution of soils reflect varied periods of sediment deposition during coastal submersion (Hoyt 1968). Soil distribution across the refuge is a result of tidal influence with barrier islands having additional inputs from sediment deposited from discharge of inland creeks that moves southwest along long shore currents (see discussion in Faustini et al. 2013:16-17 and also in van Gaalen 2004, Morton and Miller 2005, Hayes and Michel 2008). Barrier island soils are more recent depositions during the Holocene period within the last 3,500 years (Riggs et al. 2011).

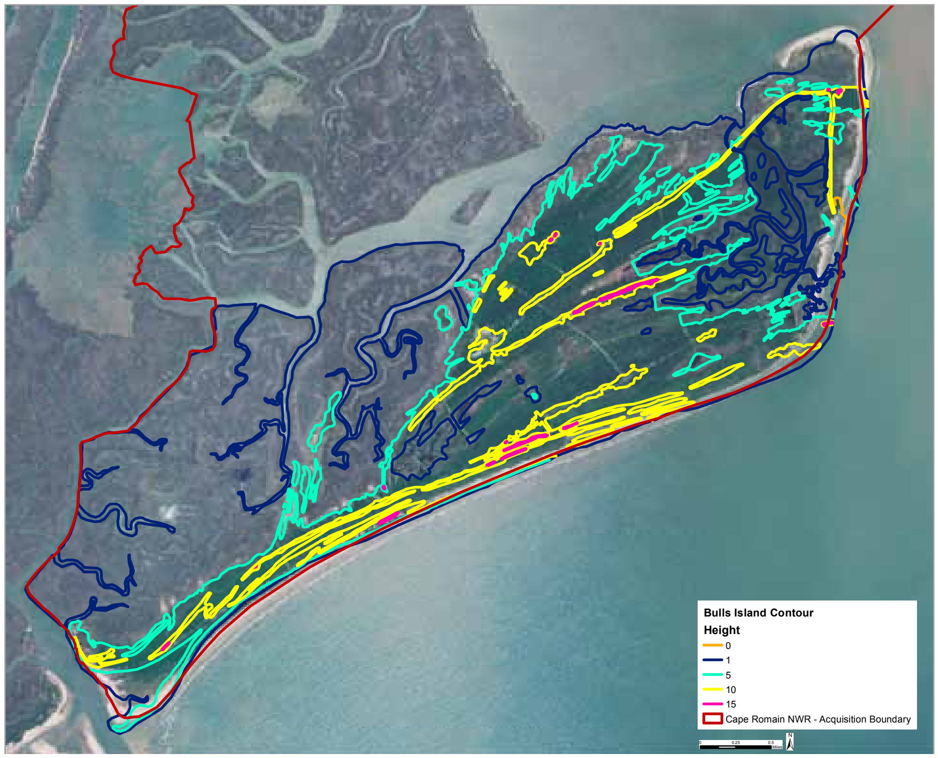


Figure 7. Shape and elevation contours (feet amsl) of Bulls Island on Cape Romain National Wildlife Refuge (data from refuge).

The four major soil associations on Cape Romain NWR are: 1) Tidal marsh, Soft; 2) Capers; 3) Crevasse-Dawhoo Complex; and 4) Rolling Coastal Beaches and Dune Land. The most extensive soil series on Cape Romain NWR is mapped as “Tidal Marsh Soft,” which covers the majority of the refuge except Cape and Bulls Islands. Tidal Marsh soils are inundated by high tides and are saturated the rest of the time. This association is typically characterized by dark soils that contain black or brown loam, clay, muck, or peat (Miller 1971). These soils are found near tidal streams and rivers and in tidal flat areas between the ocean and upland areas. Sulphur is a main constituent of these soils, becoming sulfuric acid if the area is drained or aerated (Miller 1971). Another prevalent soil type on Cape Romain NWR, Capers, occurs on Bulls and Cape Islands and a few other locations in the northeastern portion of the refuge. The Capers silty clay loam is similar to Tidal Marsh soils but has a somewhat more complex structure containing about five inches of clay loam at the surface, underlain by silty clay, which reflects a higher elevation tidal marsh environment. Capers tidal flat areas typically are inundated by seawater two to six inches deep more than once a month (Miller 1971). The Crevasse-Dawhoo soil complex occurs on Bulls Island ridges and swales; Crevasse soils are on the ridges and Dawhoo soils occur in “swales” or “troughs.” Meggett, Rutlege, Seewee, Lakland, Chipley, and Cape Fear soils are present on mainland areas, including the White and King tracts. These inland soils formed under coastal maritime forest communities with freshwater wetlands present in swales or small inland depressions. Typically, Chipley, Lakeland and Seewee soils are highly sandy and are present on higher elevations and ridges while Rutlege, Cape Fear, and Meggett soils contain more loam and clay material and occur in swales. Soils near the AIWW and on Bulls Island are mapped as ‘made land’ resulting from dredged materials that have been deposited near the waterway. Coastal beaches and dune land soils contain fine sands that typically are flooded by tides twice daily; loosely-packed dune sands remain dry (Miller 1971).

TOPOGRAPHY

The Sea Island/Coastal Marsh region of the Southern Coastal Plain identified by the EPA is

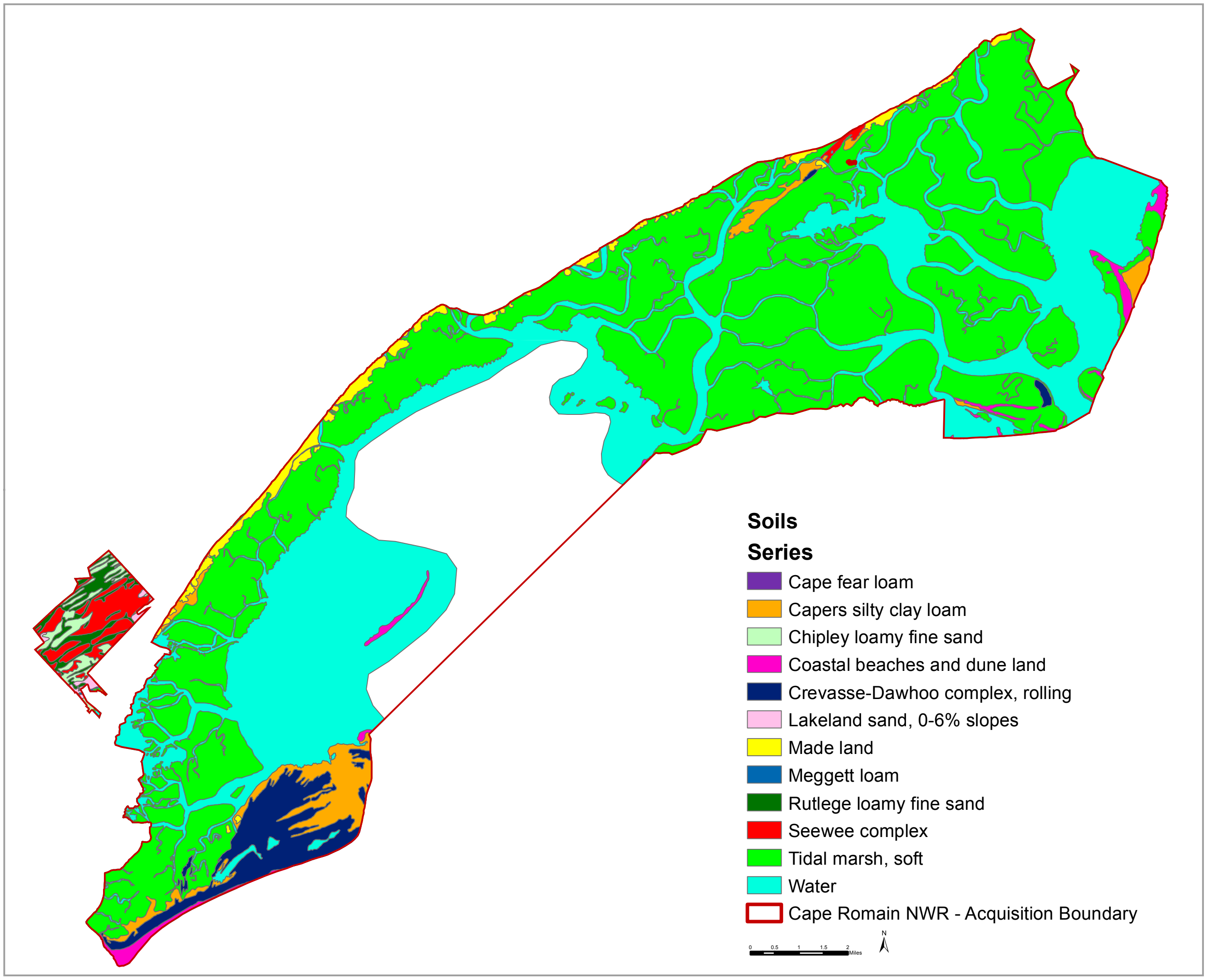


Figure 8. Soil types on Cape Romain National Wildlife Refuge (USDA SSURGO data, http://websoilsurvey.nrcs.usda.gov).

the lowest elevation area of South Carolina characterized by Quarternary materials (Figs. 4, 5). The South Carolina Coastal Plain ranges in elevation from 0 to 50 feet above sea level (National Geodetic Vertical Datum of 1929). Unconsolidated materials composed of sand, silt, and clay have been deposited and form a variety of relatively gently rolling features including beaches, dunes, marsh, terrace, and nearshore marine deposits (Fig. 9, Campbell and Coes 2010). Light Detection and Ranging (LiDAR) elevation surveys have been completed for northern Charleston County, but are not completely processed or available at this time. Currently, processed LiDAR data are only available at two-foot contour intervals (Fig. 10). This gross-level topographic data mapping precludes definition of the many modest (< 1-2 feet) elevation changes associated with coastal ridges, swales, and other depressions. The topography of this region is influenced by past processes such as tides, river discharge, hurricanes, and wind action that have a great influence on island erosion and accretion annually and over longer time periods (Daniels et al. 1993, Sexton 1995, Pilkey and Dixon 1996). Historically, the Santee River and other inland rivers and streams supplied sediments to the Cape Romain NWR region, which helped maintain beaches and landmass of islands (Hayes and Michel 2008). Common topographic features throughout the area include sequential distribution of different features such as dunes, beach ridges, tidal channels, and marshes along with other features associated with on-going processes including ebb tidal deltas, swash bars, and washover terraces.

CLIMATE AND HYDROLOGY

A complete description of the climate and major hydrological/water resource features of Cape Romain NWR, including information on projected climate change, is provided in the recently completed refuge WRIA (Faustini et al. 2013). The following discussion briefly summarizes WRIA information that is important to the HGM evaluation of ecosystem restoration and management options. The climate of the Cape Romain NWR area is characterized by humid and subtropical conditions with mild winters and hot and humid summers (Table 1). Generally, the South Carolina climate is affected by its low elevation and Bermuda High pressure systems, which pass warm and moist air over the Gulf Stream in the Atlantic Ocean creating humid conditions. Climate in the winter is affected by the Appalachian Mountains to the north and west, which buffer South Carolina from interior cooler weather.

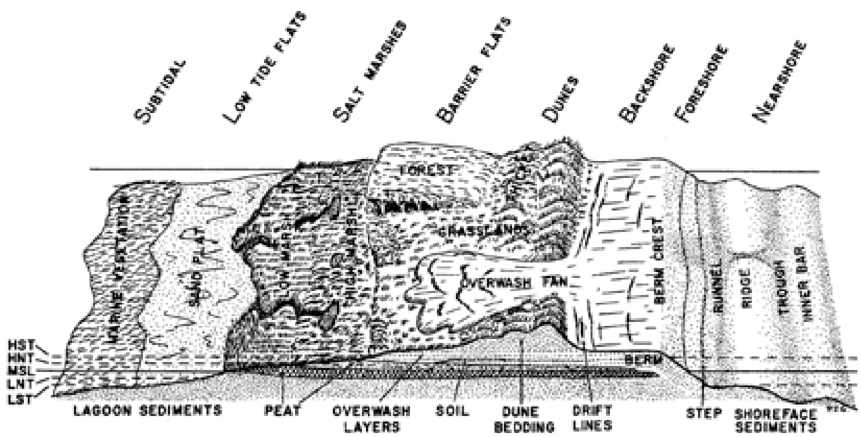


Figure 9. Cross section of barrier island topography (from Hayes and Michel 2008).

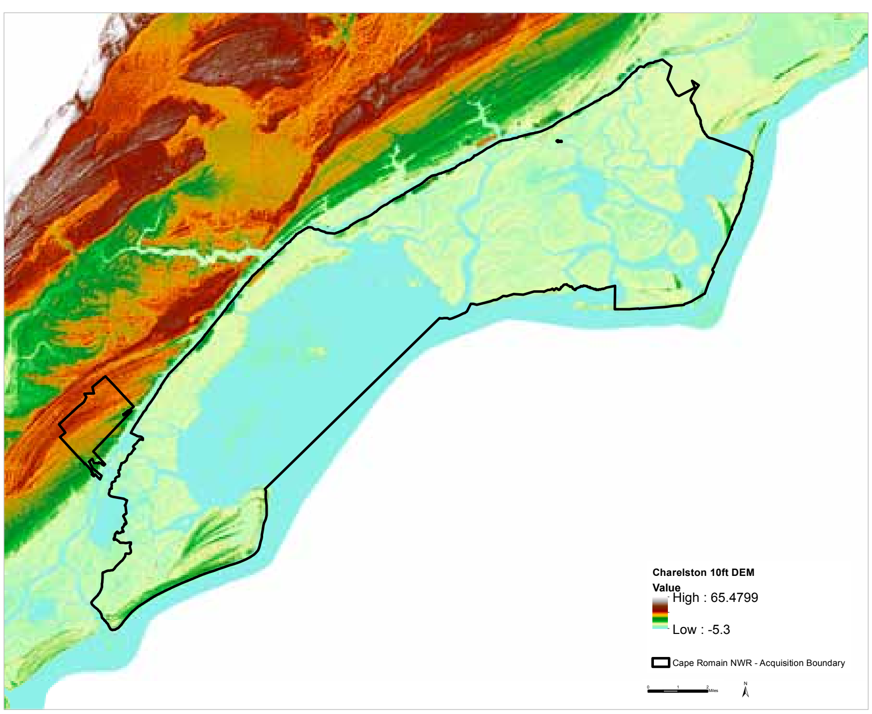


Figure 10. Digital elevation model (10 ft. DEM) for Cape Romain National Wildlife Refuge.

Large variations in average precipitation exist between the two weather reporting stations near the refuge. For example, Charleston receives an average of 46 inches/year while Georgetown receives an average of 55 inches/year (Table 2). About 15% of the regional annual precipitation is from major tropical storms (USFWS 2010) with a majority of the precipitation occurring in spring and summer months. Afternoon thunderstorms are common, occurring on average 64 days of the year. The South Carolina coast is a moderately high-risk zone for hurricanes that usually occur from August through October. These tropical storms may cause extreme destruction as was seen in September 1989 with Category 4 Hurricane Hugo. Tropical storms in the Cape Romain NWR region often produce heavy local rainfall and potentially spin-up tornadoes. Winds generally travel in a southerly direction in fall and winter and to the northeast in the spring and summer (Lynn 2010). Snow is rare in the region, but has occurred in January, February, and March. Long-term precipitation data from Charleston suggest that alternating low and high precipitation cycles recur on about 20-year intervals; however, data from Georgetown has greater variability with some indication of shorter duration cycles of 10+years and some long term wet cycles occurring between 1982 and 2002 (Fig. 11; Faustini et al. 2013). Mean annual temperature is 67^{o} Fahrenheit (F) in Charleston and

Table 1. Mean monthly and annual temperatures for: a) Charleston and b) Georgetown, South Carolina (from www.ncdc.noaa.gov.oa.climate/normals.usnormals.html). Monitoring sites are monitored as part of the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate mapping service, which is the U.S. Department of Agriculture's official source of climatological data. The PRISM data represent 1971-2000 climatological normals, although data are derived from the station records that span the 1930-2001 period.

Station: CHARLESTON CITY, SC **1971-2000** **COOP ID: 381549**

Climate Division: SC 7 **NWS Call Sign: 1549** **Elevation: 10 Feet** **Lat: 32°47N** **Lon: 79°56W**

Temperature (°F)																					
	Mean (1)			Extremes										Degree Days (1) Base Temp 65		Mean Number of Days (3)					
Month	Daily Max	Daily Min	Mean	Highest Daily(2)	Year	Day	Highest Month(1) Mean	Year	Lowest Daily(2)	Year	Day	Lowest Month(1) Mean	Year	Heating	Cooling	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
Jan	57.1	42.4	49.8	81	1949	25	61.7	1974	10	1985	21	40.4	1977	489	3	.0	.0	24.6	.1	4.4	.0
Feb	59.8	44.9	52.4	83	1962	27	58.9	1990	16	1958	17	43.3	1978	362	7	.0	.0	23.9	.1	2.4	.0
Mar	65.8	51.5	58.7	88	1977	16	65.0	1997	22	1980	3	53.7	1971	224	27	.0	.0	30.0	@	.3	.0
Apr	72.9	58.8	65.9	94	1980	23	69.2	1977	36	1982	7	61.5	1993	57	83	.0	.3	30.0	.0	.0	.0
May	79.6	67.4	73.5	99	1953	26	78.5	1998	48+	1957	5	70.5	1997	3	266	.0	1.5	31.0	.0	.0	.0
Jun	84.9	73.8	79.4	104	1985	2	85.6	1998	57+	1967	2	75.0	1997	0	431	.1	5.7	30.0	.0	.0	.0
Jul	88.5	77.0	82.8	103	1977	22	86.0	1998	65	1997	31	80.3	1974	0	551	.3	12.3	31.0	.0	.0	.0
Aug	87.1	76.1	81.6	103	1999	1	84.3	1999	59	1986	29	79.0	1976	0	514	@	9.5	31.0	.0	.0	.0
Sep	83.0	72.2	77.6	98	1985	11	81.3	1998	50	1967	30	74.1	1984	0	377	.0	3.4	30.0	.0	.0	.0
Oct	75.1	61.9	68.5	93+	1986	5	72.7	1985	39+	1962	27	63.2	1987	47	156	.0	.2	31.0	.0	.0	.0
Nov	67.6	53.4	60.5	87	1961	1	68.0	1985	17	1950	25	53.3	1976	183	47	.0	.0	29.6	.0	@	.0
Dec	60.0	45.5	52.8	81+	1998	7	59.7	1971	14	1962	13	44.5	1989	390	11	.0	.0	27.2	.1	2.5	.0
Ann	73.5	60.4	67.0	104	Jun 1985	2	86.0	Jul 1998	10	Jan 1985	21	40.4	Jan 1977	1755	2473	.4	32.9	349.3	.3	9.6	.0

Station: GEORGETOWN 2 E, SC **1971-2000** **COOP ID: 383468**

Climate Division: SC 4 **NWS Call Sign:** **Elevation: 10 Feet** **Lat: 33°22N** **Lon: 79°13W**

Temperature (°F)																					
	Mean (1)			Extremes										Degree Days (1) Base Temp 65		Mean Number of Days (3)					
Month	Daily Max	Daily Min	Mean	Highest Daily(2)	Year	Day	Highest Month(1) Mean	Year	Lowest Daily(2)	Year	Day	Lowest Month(1) Mean	Year	Heating	Cooling	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
Jan	59.6	37.2	48.4	84	1937	23	61.7	1974	6	1985	21	37.5	1977	529	3	.0	.0	26.4	.1	10.6	.0
Feb	62.8	38.7	50.8	84+	1990	3	58.4	1990	11	1943	15	40.9	1978	405	6	.0	.0	24.9	.2	7.5	.0
Mar	69.7	44.7	57.2	94	1935	21	63.2	1997	11+	1980	3	51.8	1971	264	21	.0	@	30.4	@	2.9	.0
Apr	76.5	51.0	63.8	94	1981	30	68.6	1994	28	1971	1	59.4	1983	94	56	.0	.8	30.0	.0	.2	.0
May	82.9	59.4	71.2	99+	1941	23	75.2	1991	38+	1989	8	67.9	1992	10	199	.0	3.2	31.0	.0	@	.0
Jun	87.6	66.7	77.2	106	1990	30	81.3	1981	45	1969	13	73.1	1997	0	366	.1	10.6	30.0	.0	.0	.0
Jul	90.6	70.9	80.8	105	1977	10	85.0	1993	56	1988	2	77.3	1975	0	488	.6	18.3	31.0	.0	.0	.0
Aug	89.1	69.7	79.4	104	1954	18	83.0	1987	46	1999	30	76.6	1976	0	447	.1	14.4	31.0	.0	.0	.0
Sep	85.0	65.6	75.3	101+	1944	5	78.1	1980	44+	1942	30	72.3	1984	1	311	.0	4.9	30.0	.0	.0	.0
Oct	77.3	54.9	66.1	96+	1986	5	71.6	1985	30	1976	29	60.0	1987	78	111	.0	.3	31.0	.0	.1	.0
Nov	69.9	46.4	58.2	87+	1987	3	66.4	1985	18	1950	26	51.1	1976	236	31	.0	.0	29.8	.0	2.3	.0
Dec	62.3	39.5	50.9	83	1998	8	58.8	1971	10	1943	16	42.2	1989	448	10	.0	.0	27.9	.1	8.0	.0
Ann	76.1	53.7	64.9	106	Jun 1990	30	85.0	Jul 1993	6	Jan 1985	21	37.5	Jan 1977	2065	2049	.8	52.5	353.4	.4	31.6	.0

\+ Also occurred on an earlier date(s)

@ Denotes mean number of days greater than 0 but less than .05

Complete documentation available from: www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

(1) From the 1971-2000 Monthly Normals

(2) Derived from station's available digital record: 1930-2001

(3) Derived from 1971-2000 serially complete daily data

Table 2. Mean monthly and annual precipitation for: a) Charleston and b) Georgetown, South Carolina (from www.ncdc.noaa.gov.oa.climate/normals.usnormals.html). Monitoring sites are monitored as part of the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate mapping service, which is the U.S. Department of Agriculture's official source of climatological data. The PRISM data represent 1971-2000 climatological normals, although data are derived from the station records that span the 1930-2001 period.

Station: CHARLESTON CITY, SC **COOP ID: 381549**

Climate Division: SC 7 **NWS Call Sign: 1549** **Elevation: 10 Feet** **Lat: 32°47N** **Lon: 79°56W**

Precipitation (inches)

	Precipitation Totals									Mean Number of Days (3)				Precipitation Probabilities (1) Probability that the monthly/annual precipitation will be equal to or less than the indicated amount										
	Means/ Medians(1)		Extremes							Daily Precipitation				Monthly/Annual Precipitation vs Probability Levels. These values were determined from the incomplete gamma distribution										
Month	Mean	Med-ian	Highest Daily(2)	Year	Day	Highest Monthly(1)	Year	Lowest Monthly(1)	Year	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	.95
Jan	3.62	4.07	2.57	1964	12	6.44	1991	.86	1985	10.1	6.5	2.5	.7	1.06	1.40	1.92	2.37	2.80	3.26	3.76	4.35	5.12	6.32	7.44
Feb	2.62	2.38	2.56	1998	16	7.26	1998	.50	1994	8.0	4.9	1.9	.7	.59	.83	1.21	1.56	1.90	2.27	2.69	3.18	3.83	4.87	5.84
Mar	3.83	3.25	3.45	1993	23	9.79	1983	1.02	1995	8.5	5.8	2.8	1.0	1.28	1.65	2.18	2.63	3.06	3.51	4.00	4.57	5.30	6.43	7.48
Apr	2.44	2.33	3.67	1997	28	6.33	1997	.00	1972	7.0	4.6	1.6	.6	.31	.62	1.03	1.38	1.73	2.10	2.52	3.01	3.67	4.71	5.70
May	2.77	1.91	5.40	1976	23	11.93	1976	.02	2000	7.6	4.7	1.8	.7	.25	.44	.81	1.19	1.61	2.09	2.66	3.37	4.35	5.99	7.60
Jun	4.96	3.69	10.38	1973	11	19.24	1973	.98	1978	10.6	6.4	3.0	1.4	.69	1.09	1.80	2.49	3.21	4.01	4.93	6.06	7.58	10.07	12.47
Jul	5.50	5.39	5.89	1950	8	12.81	1990	.54	1986	11.4	7.7	3.8	1.7	1.19	1.70	2.51	3.24	3.97	4.75	5.63	6.68	8.06	10.27	12.36
Aug	6.54	5.28	5.39	1981	19	16.37	1971	.60	1980	11.9	8.7	3.9	2.1	.98	1.53	2.47	3.38	4.32	5.35	6.54	7.99	9.94	13.12	16.17
Sep	6.13	5.22	8.50	1998	21	14.96	1987	.51	1985	9.7	6.8	3.1	1.6	.87	1.38	2.26	3.11	4.00	4.98	6.11	7.49	9.36	12.40	15.33
Oct	3.02	1.85	6.79	1965	18	11.20	1994	.00	2000	6.1	4.1	1.7	.8	.07	.25	.64	1.06	1.54	2.11	2.79	3.67	4.89	6.98	9.05
Nov	2.18	2.03	6.65	1969	1	5.60	1972	.21	1996	7.0	4.0	1.4	.6	.28	.45	.76	1.06	1.38	1.74	2.15	2.66	3.35	4.49	5.59
Dec	2.78	2.78	2.49	1971	3	5.53	1976	.49	1984	9.0	5.4	2.1	.6	.77	1.04	1.44	1.78	2.13	2.48	2.88	3.34	3.95	4.90	5.78
Ann	46.39	45.86	10.38	Jun 1973	11	19.24	Jun 1973	.00+	Oct 2000	106.9	69.6	29.6	12.5	32.43	35.12	38.57	41.19	43.53	45.79	48.12	50.71	53.86	58.43	62.38

Snow (inches)

	Snow Totals														Mean Number of Days (1)								
	Means/Medians (1)				Extremes (2)										Snow Fall >= Thresholds					Snow Depth >= Thresholds			
Month	Snow Fall Mean	Snow Fall Median	Snow Depth Mean	Snow Depth Median	Highest Daily Snow Fall	Year	Day	Highest Monthly Snow Fall	Year	Highest Daily Snow Depth	Year	Day	Highest Monthly Mean Snow Depth	Year	0.1	1.0	3.0	5.0	10.0	1	3	5	10
Jan	.1	.0	#	0	.7	1977	31	.8	1977	1	1977	31	#	1977	-9.9	-9.9	-9.9	-9.9	-9.9	.1	.0	.0	.0
Feb	.3	.0	#	0	2.1	1979	18	2.2	1979	2	1979	18	#	1979	-9.9	-9.9	-9.9	-9.9	-9.9	.1	.0	.0	.0
Mar	.2	.0	#	0	1.3	1980	2	1.3	1980	1	1980	3	#	1980	.1	.1	.0	.0	.0	.0	.0	.0	.0
Apr	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
May	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	-9.9	-9.9	-9.9	-9.9	-9.9	.0	.0	.0	.0
Jun	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jul	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	-9.9	-9.9	-9.9	-9.9	-9.9	.0	.0	.0	.0
Aug	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	-9.9	-9.9	-9.9	-9.9	-9.9	.0	.0	.0	.0
Sep	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	-9.9	-9.9	-9.9	-9.9	-9.9	.0	.0	.0	.0
Oct	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	-9.9	-9.9	-9.9	-9.9	-9.9	.0	.0	.0	.0
Nov	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9
Dec	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9
Ann	.6	.0	N/A	N/A	2.1	Feb 1979	18	2.2	Feb 1979	2	Feb 1979	18	#+	Mar 1980	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9

+ Also occurred on an earlier date(s) #Denotes trace amounts

@ Denotes mean number of days greater than 0 but less than .05

-9/-9.9 represents missing values
Annual statistics for Mean/Median snow depths are not appropriate

(1) Derived from Snow Climatology and 1971-2000 daily data

(2) Derived from 1971-2000 daily data

Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

Continued next page

Table 2, cont'd. Mean monthly and annual precipitation for: a) Charleston and b) Georgetown, South Carolina (from www.ncdc.noaa.gov.oa.climate/normals.usnormals.html). Monitoring sites are monitored as part of the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate mapping service, which is the U.S. Department of Agriculture's official source of climatological data. The PRISM data represent 1971-2000 climatological normals, although data are derived from the station records that span the 1930-2001 period.

1971-2000

Station: GEORGETOWN 2 E, SC **COOP ID: 383468**

Climate Division: SC 4 **NWS Call Sign:** **Elevation: 10 Feet** **Lat: 33°22N** **Lon: 79°13W**

Precipitation (inches)

	Precipitation Totals									Mean Number of Days (3)				Precipitation Probabilities (1) Probability that the monthly/annual precipitation will be equal to or less than the indicated amount										
	Means/Medians(1)		Extremes							Daily Precipitation				Monthly/Annual Precipitation vs Probability Levels These values were determined from the incomplete gamma distribution										
Month	Mean	Med-ian	Highest Daily(2)	Year	Day	Highest Monthly(1)	Year	Lowest Monthly(1)	Year	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	.95
Jan	4.66	4.47	3.80	1999	24	10.69	1998	1.60	1981	10.2	7.4	3.5	1.3	1.86	2.29	2.90	3.40	3.88	4.36	4.88	5.49	6.25	7.42	8.49
Feb	3.41	2.58	5.03	1940	10	12.52	1998	.59	1976	8.2	5.9	2.5	1.1	.68	.99	1.49	1.95	2.41	2.91	3.47	4.14	5.04	6.47	7.83
Mar	4.00	4.11	3.70	1953	12	10.51	1983	.84	1982	8.6	5.7	2.7	1.3	1.48	1.85	2.39	2.84	3.27	3.71	4.19	4.74	5.45	6.53	7.53
Apr	2.67	2.39	2.70	1982	26	7.98	1982	.05	1972	6.7	4.6	1.8	.9	.23	.41	.77	1.14	1.54	2.01	2.56	3.25	4.20	5.79	7.36
May	4.21	3.42	4.40	1992	30	9.53	1992	.61	1982	8.1	5.5	2.7	1.4	.82	1.20	1.82	2.39	2.97	3.58	4.29	5.13	6.25	8.05	9.75
Jun	5.63	5.09	10.56	1945	25	11.99	1994	1.40	1978	9.8	7.0	3.8	1.7	1.94	2.47	3.24	3.90	4.53	5.17	5.88	6.70	7.75	9.38	10.88
Jul	6.13	6.06	5.04	1959	9	15.69	1996	.12	1987	11.0	7.9	3.9	1.8	1.24	1.79	2.69	3.52	4.35	5.24	6.24	7.45	9.06	11.62	14.05
Aug	7.40	6.31	8.55	1995	28	19.49	1971	.99	1997	12.3	9.1	4.3	2.3	1.25	1.89	2.97	3.98	5.03	6.16	7.46	9.03	11.14	14.54	17.79
Sep	6.64	5.50	11.89	1999	16	17.31	1999	.58	1981	10.2	6.4	3.5	2.0	.83	1.36	2.30	3.23	4.21	5.29	6.56	8.12	10.23	13.71	17.07
Oct	4.26	3.04	8.80	1954	15	12.59	1971	.00	2000	6.4	4.4	2.3	1.2	.12	.42	.99	1.60	2.28	3.07	4.01	5.20	6.86	9.66	12.43
Nov	3.25	3.01	4.90	1985	22	11.70	1985	.65	1996	7.7	5.0	2.0	1.0	.71	1.00	1.48	1.91	2.35	2.81	3.33	3.95	4.77	6.08	7.31
Dec	3.94	4.14	4.70	1964	27	10.34	1994	.75	1984	8.8	5.8	2.6	1.3	.85	1.21	1.79	2.31	2.84	3.40	4.03	4.78	5.77	7.36	8.85
Ann	56.20	55.92	11.89	Sep 1999	16	19.49	Aug 1971	.00	Oct 2000	108.0	74.7	35.6	17.3	39.40	42.63	46.79	49.95	52.76	55.48	58.29	61.41	65.19	70.68	75.44

Snow (inches)

Snow Totals															Mean Number of Days (1)								
Means/Medians (1)					Extremes (2)										Snow Fall >= Thresholds					Snow Depth >= Thresholds			
Month	Snow Fall Mean	Snow Fall Median	Snow Depth Mean	Snow Depth Median	Highest Daily Snow Fall	Year	Day	Highest Monthly Snow Fall	Year	Highest Daily Snow Depth	Year	Day	Highest Monthly Mean Snow Depth	Year	0.1	1.0	3.0	5.0	10.0	1	3	5	10
Jan	.2	.0	0	0	4.0	1988	15	4.0+	1988	0	0	0	0	0	@	@	@	.0	.0	.0	.0	.0	.0
Feb	.1	.0	0	0	3.0	1973	10	3.0	1973	9	1973	11	1	1973	.1	.1	@	.0	.0	@	@	.0	.0
Mar	.2	.0	0	0	4.0	1980	2	4.0	1980	0	0	0	0	0	@	@	@	.0	.0	.0	.0	.0	.0
Apr	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
May	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jun	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jul	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Aug	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Sep	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Oct	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Nov	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Dec	#	.0	0	0	#	1988	12	#+	1988	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ann	.5	.0	N/A	N/A	4.0+	Jan 1988	15	4.0+	Jan 1988	9	Feb 1973	11	1	Feb 1973	.1	.1	@	.0	.0	@	@	.0	.0

+ Also occurred on an earlier date(s) #Denotes trace amounts

@ Denotes mean number of days greater than 0 but less than .05

-9/-9.9 represents missing values
Annual statistics for Mean/Median snow depths are not appropriate

(1) Derived from Snow Climatology and 1971-2000 daily data

(2) Derived from 1971-2000 daily data

Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

65° F in Georgetown with about 240 frost-free (growing season) days.

The hydrologic regime of the Cape Romain NWR region is complex with fresh and seawater inputs derived through both surface and groundwater interactions. The refuge lies adjacent to the outlet of the Santee River Basin, which is the second largest watershed basin in the eastern coastal area (Hughes 1994; http://water.usgs.gov/wsc/sub/0305.html); the Santee River empties into the Atlantic Ocean approximately five miles north of Cape Romain NWR. The Santee River's head-waters are located in the mountains of North Carolina with the main stem channel formed by the confluence of the Wateree and Congaree rivers in central South Carolina. Many other creeks provide freshwater inputs to the Cape Romain NWR region from the mainland in addition to brackish creeks associated with the ebb and flow of tides (Fig. 12). High peak flows in the Santee River were historically greatest in February (Campbell et al. 2011). Post-dam river discharge for the period 1986 to 2011 has generally peaked in March, with mean monthly March flows averaging 17,900 cfs and ranging from 3,566 to 43,460 cfs below Jamestown, South Carolina (Table 3). The highest monthly streamflow for this period, 50,000 cfs, occurred in February 1998.

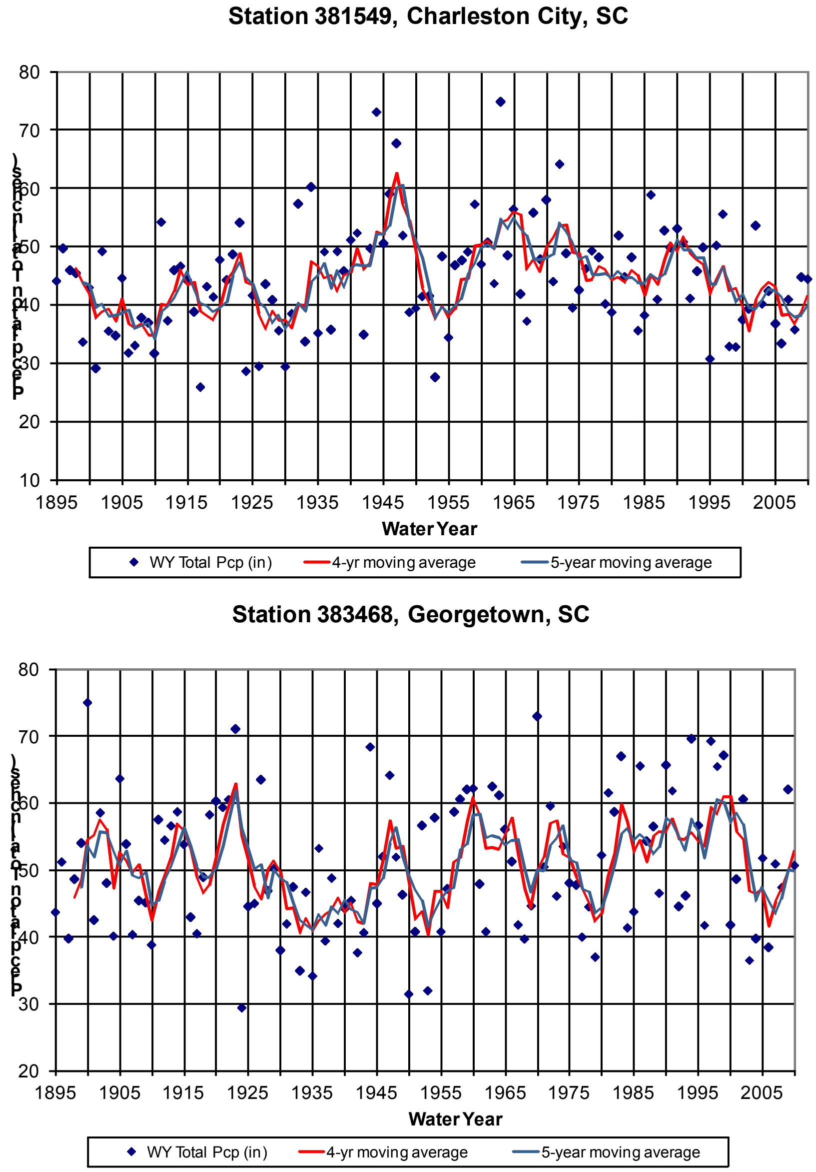
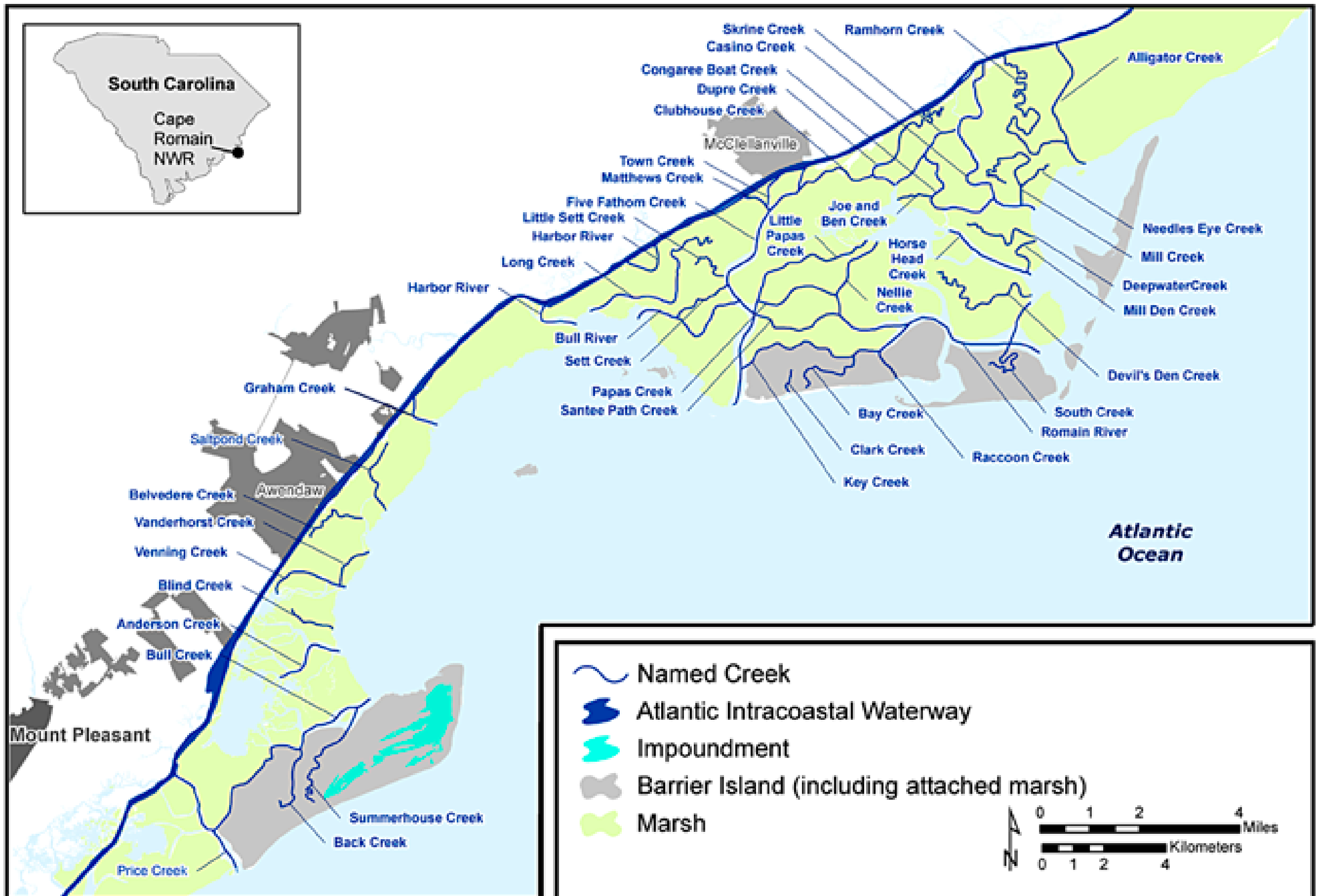


Figure 11. Total water year precipitation from 1895-2010 at Charleston and Georgetown, South Carolina (from Faustini et al. 2013).

Tides at Cape Romain NWR are semi-diurnal comprised of two high and two low tides each lunar day (Lynn 2010). The tidal range at Cape Romain NWR is 1.6 m for neap tides and 1.9 m for spring tides, with the "average significant wave height" of 1.3 + 0.7 m (Harris et al. 2005, Faustini et al. 2013). Historically, tides could ascend rivers up to 35 miles upstream from the coast and may have reached farther during periods of drought (Ramsay 1858). However, because of more recent freshwater flows, tides rarely get more than two miles upstream on the Santee River. Creeks and rivers on the Cape Romain NWR are tidal with most being classified as coastal (Faustini et al. 2013).

The Coastal Plain in South Carolina has been divided into a lower and upper plain based on groundwater flow and aquifer discharge (Fig. 13; Aucott and Speiran 1985). Six groundwater aquifers associated with the lower coastal plain were identified by Aucott (1996) ranging from the surficial Pleistocene aquifer comprised of coastal terrace deposits that are up to 40 feet in depth to the Late Cretaceous Cape Fear Formation Aquifer that is over 1,600 feet deep (Table 4, Fig. 14; Aucott and Speiran 1985; Harwell et al. 2004). Other detailed hydrostratigraphy identified eight aquifers separated by seven intervening confining



Map Date: 9/25/2013 File: Fig9-CRTidalCreeksWaterbodies.mxd Data Source: USFWS Digitized Named Stream Centerlines, Impoundments, Barrier Islands and Marsh; NHD Flowlines, ESRI Map Service.

Figure 12. Major waterways and rivers in the Cape Romain National Wildlife Refuge region (from Faustini et al. 2013).

layers (Campbell and Coes 2010). Of these, five aquifers are dominated by sand and are confined by layers of clay, silt, or low permeability limestone. The Floridan Aquifer is confined and defined in large part by impermeable limestone characterized by carbonates with some areas of bioclastic limestone that provides clean and available water resources (Harwell et al. 2004). This aquifer lies directly below the surficial aquifer along the coastline (Fig. 14; Hughes et al. 2000). A majority of the recharge to the aquifer occurs from precipitation in areas where formations occur as outcrops in the region, for example, the Floridan Aquifer outcrops near the Santee River. In addition, downward leakage occurs from upper aquifers to lower ones as some confining beds have high permeability. Discharge from the aquifers to rivers and creeks occurs more often in the upper coastal plain than in the lower resulting from several factors including higher permeabilities in aquifer sediments, rates of recharge, and potentiometric gradients (Aucott and Speiran 1985). Groundwater flow within the lower coastal plain differs dependent on aquifer system. The Floridan and Tertiary systems flow patterns are toward the coast and somewhat towards major rivers while those below are more sluggish and flow towards the east, loosely paralleling the coastline, specifically near the Cape Romain NWR area (Fig. 15, Aucott and Speiran 1985).

PLANT AND ANIMAL COMMUNITIES

Historically, Cape Romain NWR contained a variety of habitat types including tidal creeks and flats, emergent estuarine marsh, sand beaches and dunes, maritime forest, a small area of upland forest, and small freshwater wetland depressions. While the general distribution of major communities historically present at Cape Romain NWR is known, detailed information about species-specific distribution during the Pre-settlement period is limited and only a few U.S. Coast Survey historical maps are available (e.g., Appendix I in Faustini et al. 2013). Inference from other ACP areas and vegetation abiotic-biotic relationships (e.g., Harper 1911, Bratton 1985, Nelson 1986, Bellis and Keough 1995) form the basis for understanding historical distribution and community composition. A brief summary of Cape Romain NWR habitats is provided below.

Historical botanical accounts document large contiguous areas of forests along the South Carolina Coast composed of oak and pine species (Ramsay 1858). Low elevation areas immediately adjacent to the coast and on barrier islands contained diverse oak-pin-magnolia maritime forest (Bellis and Keough 1995), while higher elevation mainland areas contained upland forests dominated by pine, especially longleaf pine (*Pinus palustris*) (Croker 1987). Maritime forests occurred on lower elevation areas that often were poorly drained; these areas were dominated by loblolly pine (*Pinus taeda*), wax myrtle (*Morella cerifera*), yaupon holly (*Ilex vomitoria*), groundsel tree (*Baccharis halimifolia*), red cedar (*Juniperus virginiana*), and live oak (*Quercus virginiana*). On low elevation mainland areas, maritime forests also had some interspersed sweetgum (*Liquidambar styraciflua*), water oak (*Quercus nigra*), and sweetbay (*Magnolia virginiana*). In contrast, upland mainland forests occurred on well drained sandy soils (such as Chipley, Lakeland, Seewee types on the White and King tracts of Cape Romain NWR) and had extensive coverage by longleaf pine along with interspersed loblolly pine and several species of hardwoods. In many areas, the longleaf forest areas were open and park-like (Croker 1987).

Lower elevation swales and depressions in maritime forests contained loamy and clay soils (Rutlege, Cape Fear, Meggett soils types) that supported more oaks and water tolerant species along with small scattered freshwater wetland depressions. On Bulls Island, the historic maritime forest contained predominantly Crevasse-Dawhoo soils (Fig. 8) and was dominated by live oak, southern magnolia (*Magnolia grandiflora*), and cabbage palm (*Sabal minor*); little endemic pine was present (Helms et al. 1991). The understory of maritime forests on both islands and the mainland contains red bay (*Persea palustris*), yaupon holly, wax myrtle and saw palmetto (*Serenoa repens*). Crevasse soils occur on ridges on Bulls Island while Dawhoo soils are in swales. Loblolly and slash pine (*Pinus*

Table 3. Mean monthly streamflow in cubic-feet/second on the Santee River below Jameston, South Carolina from 1986 to 2011 (from www.usgs.gov).

YEAR	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986										1,412	7,384	22,870
1987	21,990	24,590	40,770	19,950	8,312	1,731	3,919	2,690	10,690	1,901	2,090	10,190
1988	16,160	7,838	3,566	2,067	1,067	842.8	853	937.2	1,379	1,614	2,557	5,333
1989	3,082	3,238	22,600	20,280	11,690	4,579	14,930	9,154	4,864	23,090	10,170	20,230
1990	15,890	20,860	23,640	15,300	6,899	5,151	970.2	2,605	6,441	34,380	19,550	10,250
1991	24,130	15,450	19,540	26,130	26,770	3,488	3,027	25,120	6,004	3,796		6,078
1992	8,572	7,114	20,160	12,070	10,970	16,220	7,530			17,360	18,950	27,870
1993						6,991	1,167			868.3	1,853	9,921
1994	14,760	12,560	19,160	13,900	2,982	4,908	8,743	16,190	13,390	12,330	7,932	19,790
1995	21,490	12,560	26,250	5,316	1,838	9,949	9,124	6,536	16,260	16,910	22,410	17,900
1996	16,070	24,750	22,120	15,760	8,292	6,500	2,296	6,026	8,522	10,580	1,638	15,260
1997	11,150	14,890	23,560	13,050	13,850	8,318	7,488	7,833	1,264	1,678	13,180	11,880
1998	26,400	50,000	35,670	29,470	21,440	5,864	1,093	4,418	8,177	2,390	1,553	5,878
1999	14,520	14,960	7,106	3,397	3,722	1,323	1,736	1,011	1,020	1,047	1,492	2,192
2000	7,425	12,680	10,820	12,200	1,606	973.4	930.8	902.9	938.5			
2001						1,335			1,265	1,254		886.5
2002	848	927.6	1,014	1,052	1,125	1,165		1,023	1,184	1,524	3,184	13,770
2003	10,630	8,930	43,460	46,750	24,570	29,840	28,620	25,170	7,312	2,931	4,381	8,453
2004	5,790	10,120	6,539	1,724	1,974	1,624	3,802	4,306	31,020	14,080	8,581	15,310
2005	13,230	2,559	12,960	21,100	5,061	11,570	16,090	8,114	2,657	5,662	2,431	13,110
2006	17,090			1,435	1,062	1,232	1,270	862.8		1,151	7,953	12,480
2007	22,730	11,440	21,740	4,294	2,379	990	935.4	809.5	727.2		672.7	642.1
2008	654.5	708.7	820.1	1,416	944.2	753.5			760.7	732.5		
2009	8,532	833.9	13,170	13,880	6,103			764.5			10,030	
2010		38,010	12,540	9,214	3,291		1,033		927	927.9	855.8	945.6
2011	2,596	1,462	6,570	9,506	782.6	695	606.5	636.1	590.5	570.3		
Mean	12,900	13,500	17,900	13,000	7,250	5,480	5,530	6,260	5,970	6,880	7,090	11,400

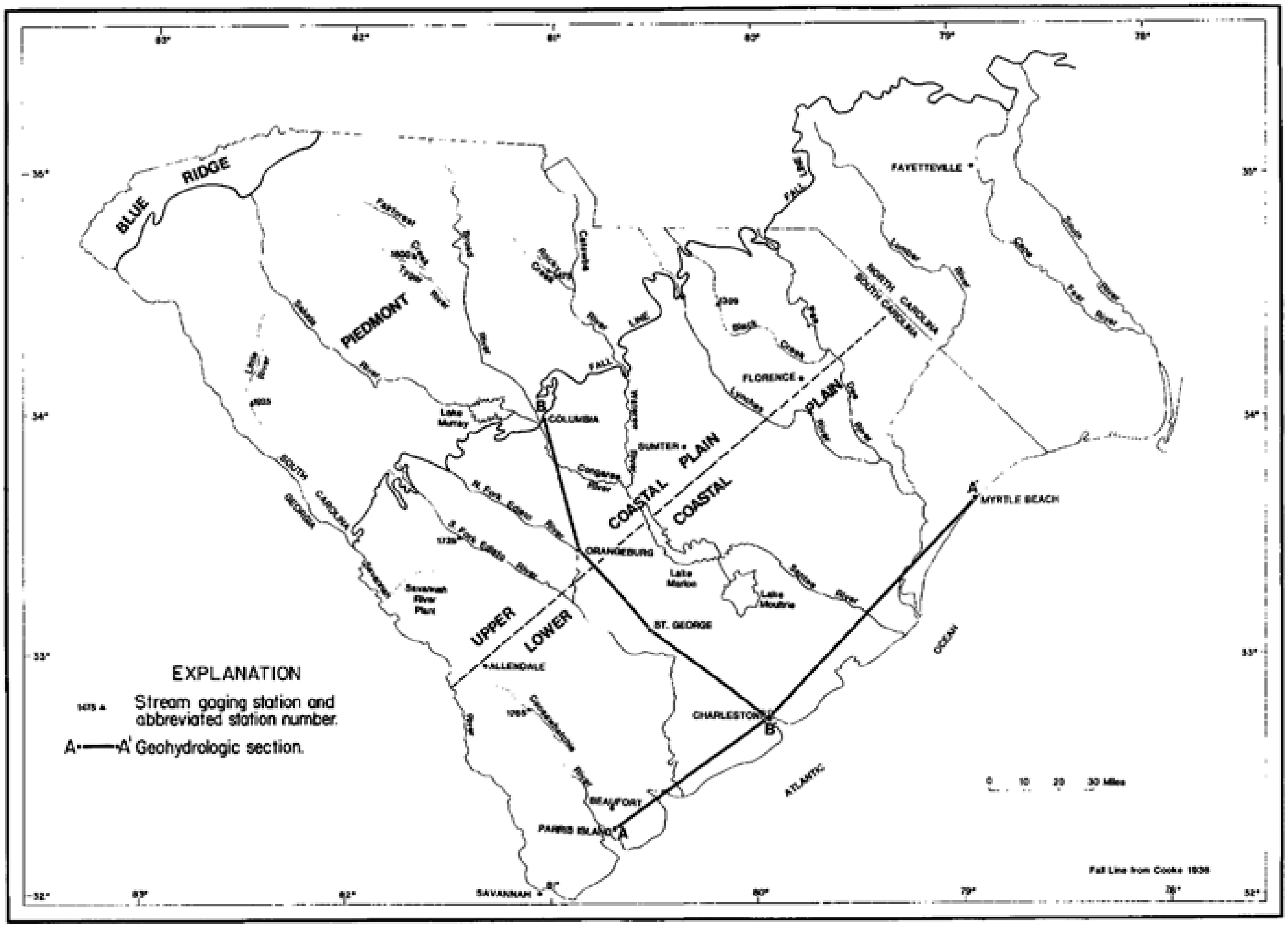


Figure 13. Location of the Upper and Lower Coastal Plains in South Carolina (from Aucott and Speiran 1985).

elliottii) currently are interspersed on Bulls Island, with larger stands of pine present along the edges of upland areas of the island.

Maritime forests historically were impacted by storms and perhaps to some limited degree in mainland coastal areas by wild fires that ranged from drier upland areas into the lower coastal zones. Little, if any, fires occurred on barrier islands and consequently, fire generally did not influence maritime forest composition on the islands (Bellis and Keough 1995, USFWS 2010). In contrast, the upland forests dominated by longleaf pine were a "fire climax" community with regular recurrence of sometimes-extensive fires (Croker 1987). Margins of maritime forests contained narrow bands of maritime shrub/scrub (S/S), usually adjacent to both fresh or brackish water wetlands and estuaries.

Vegetation communities along the coast historically contained extensive areas of emergent estuarine marsh (Harper 1911, Nifong 1998). Emergent estuarine marshes historically were, and currently remain, the dominant habitat type (about 75% of non-bay or open water area) on Cape Romain NWR and can be differentiated into "high" and "low" marsh types based on inundation frequency, sediment, and vegetation composition. Low marshes typically have silt-mud substrates, are subject to daily tidal interchange, and are dominated by smooth cordgrass (*Spartina alterniflora*). High salt marsh occurs on sandy substrates, has infrequent tidal inundation, and contains dominant glasswort (*Salicornia virginiana*), saltgrass (*Distichlis spicata*), pickleweed (*Salicornia* spp.), and mixed cordgrass species (*Spartina alterniflora, S. patens, S. cynosuroides, S. Bakeri*). Tidal flats occur on the extreme higher portions of tidally influenced coastlines where seawater inundates the site up to six inches at least once per month (Miller 1971). Historically, rains in the upstream Santee River drainage discharged into Cape Romain NWR estuaries through many labyrinth streams and creeks and the freshwater temporarily lowered salinities, which provided conditions suitable for plants and animals that prefer fresher water regimes. Alternatively during dry periods, less freshwater flowed to the coastal marshes and bays, which caused increases in local salinity and encouraged more interchange from species in and out of the Atlantic Ocean. Cape Romain NWR contains over 50 named and unnamed streams and creeks, all of which are tidally influenced (Fig. 12, Faustini et al. 2013). These creeks are classified as "coastline creeks" where both banks of the creek are represented separately and they run over 471 miles (Faustini et al. 2013).

Sand beaches and dunes formed along the Atlantic Ocean side of barrier islands. Historically, at least 16 miles of beaches were present at Cape Romain NWR. Larger beach areas include those on Bulls, Marsh, Cape, and Lighthouse islands; at White Bank; and on Raccoon Key. The popularly photographed "Boneyard Beach" on Bulls Island is a three-mile stretch where downed oak, cedar, and pine trees are strewn on the beach by in-coming surf. Historically, island beaches were supplied with sand and other sediments brought to the regional bays and coastlines by rivers and creeks, especially the large Santee River (Hayes and Michel 2008). Shell rakes also form along bays and islands where currents deposited shells. Vegetation species typical of the sand beaches and dunes within Cape Romain NWR include the endangered seabeach amaranth (*Amaranthus pumilus*), seabean (*Mucuna* spp.), and many xerophytes including bitter panicgrass (*Panicum amarum*), sea purslane (*Sesuvium portulacastrum*), fimbry (*Fimbristylis caroliniana*), and others. Dunes contain some cordgrass along with sea oats (*Uniola paniculata*), paspalum (*Paspalum* spp.), morning glory (*Ipomoea sagittata*), partridge pea (*Cassia fasciculate*), and umbrella grass (*Dichromena colorata*).

Historically, a few small freshwater "ponded" wetland depressions between dune ridges on Bulls Island provided wetland habitat interspersed with maritime forest. For example, some sort of "swale-type" wetland depressions apparently were present in the Big, House, and Summerhouse pond areas based on late 1800s U.S. Coastal surveys. The largest of these historical freshwater swales on Bulls Island are now impounded with dikes and levees. Freshwater wetlands had seasonally dynamic flooding and drying regimes based on annual onsite precipitation and local runoff, and likely contained variable amounts and zones of seasonally herbaceous, persistent emergent, and open-water submergent aquatic plant communities depending on size and wetness. Some pond areas likely also contained a shrub/scrub perimeter where the pond merged with upland maritime forest.

Recognizing the historical coastline dynamics at Cape Romain NWR, we prepared a hydrogeomorphic

Table 4. Geohydrologic correlation chart (from Aucott and Speiran 1985).

Aquifer unit	*Age of sediments*	*Geologic formations*[a]
Surficial	Pleistocene	Coastal terrace deposits
Floridan[b]	Eocene	Ocala Limestone Santee Limestone[c]
Tertiary sand	Eocene	Barnwell Formation McBean Formation Congaree Formation
Black Creek	Late Cretaceous	Black Creek Formation
Middendorf	Late Cretaceous	Middendorf Formation
Cape Fear	Late Cretaceous	Cape Fear Formation

a These are geologic formations that are generally associated with a given aquifer. However, a given aquifer may not consist of the same formations in all areas, and locally an aquifer may consist of parts of additional formations not listed.
b Carbonate equivalent of the Tertiary sand aquifer.
c As a result of the criteria used by Miller (1984) to define the Floridan aquifer system, the updip parts of the Santee Limestone are included within the Tertiary sand aquifer.

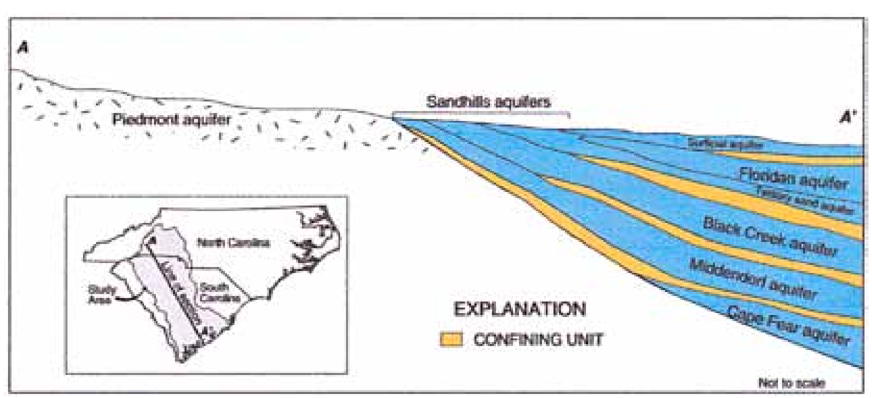


Figure 14. Location of groundwater aquifers in the Lower Coastal Plain of South Carolina (from Hughes et al. 2000).

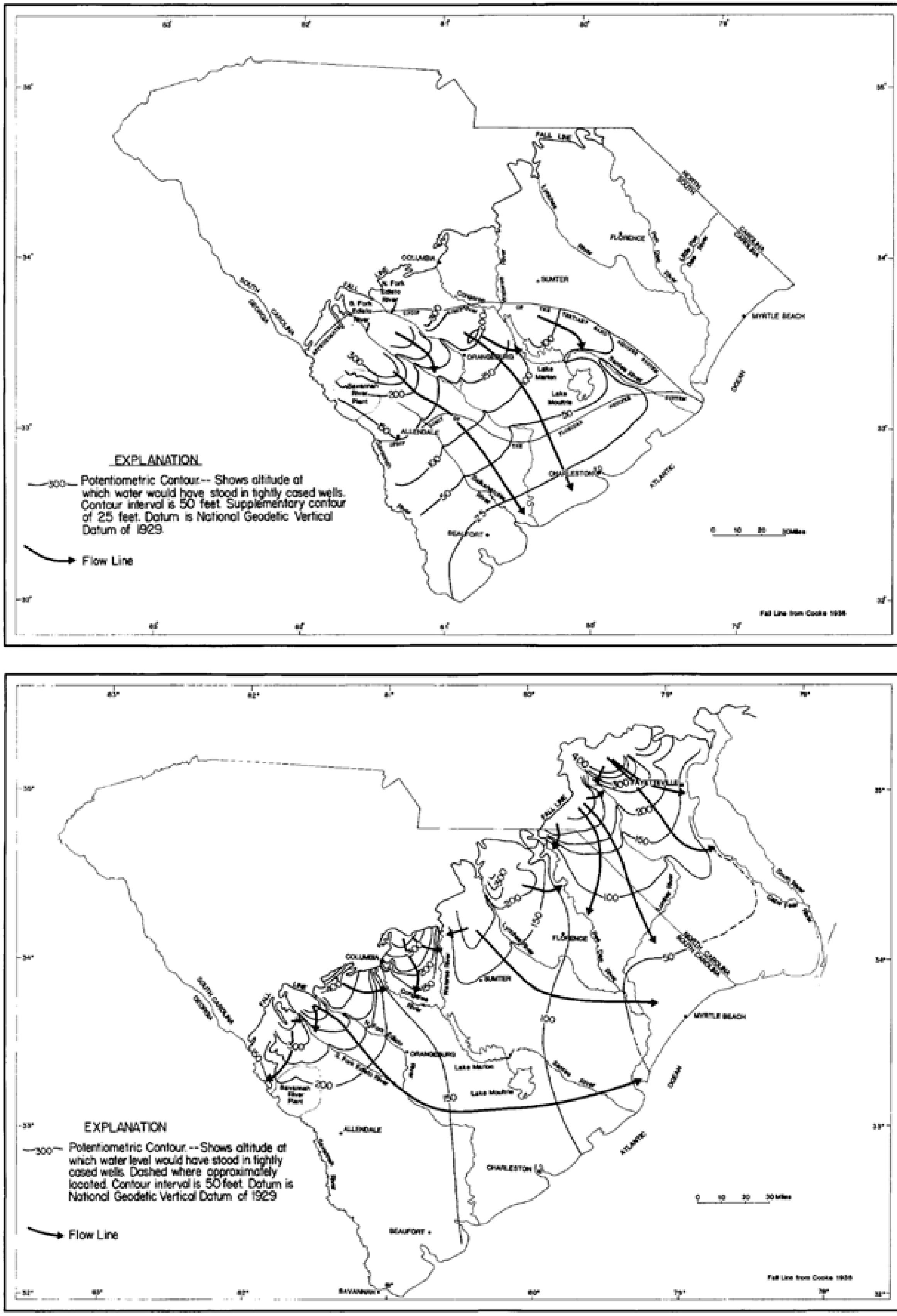


Figure 15. Groundwater flow patterns in different aquifers in South Carolina (from Aucott and Speiran 1985).

matrix of relationships of the above major plant communities to geomorphic surface, soil, general topographic position, and hydrology on current refuge lands using known association of communities with these attributes for the Cape Romain ecosystem (Table 5, Appendix A). The conceptual development of a "hydrogeomorphic community matrix" is based on empirically interpreted data from various scientific studies of plant ecology and distribution, historical maps and surveys, and current site-specific reference sites (see discussion in Klimas et al. 2009, Theiling et al. 2012, Heitmeyer et al. 2013). These interpreted correlations between plant species/communities and abiotic ecosystem attributes are in effect the basis of plant biogeography and physiography whereby information is sought on where plant species and community assemblages occur throughout the world relative to geology and geomorphic setting, soils, topographic and aspect position, and hydrology (e.g., Barbour and Billings 2000). The development of a "hydrogeomorphic matrix" then allows distribution maps of potential historic vegetation communities at Cape Romain NWR to be produced (Fig. 16) based on the botanical correlations that identify community type and distribution, juxtaposition, and "driving" ecological processes that are most influential in community formation and sustainability. The predictions of type and historic distribution of communities are only as accurate as the understanding and documentation of plant-abiotic relationships and the geospatial data for the abiotic variables for a location and period of interest, such as pre-settlement period.

In general, the combination of coastal island and shoreline geomorphology, soils, and elevation is

Table 5. Hydrogeomorphic (HGM) matrix of historical distribution of vegetation communities/habitat types on Cape Romain NWR Complex units. Relationships were determined from old aerial photographs, geomorphic landform, soil maps (Fig. 8), various historical botanical accounts of the region (see e.g., Harper 1911, Bratton 1985, Helms et al. 1991, Bellis and Keough 1995), and land cover maps (Figs. 23, 24).

Community/ habitat type	Geomorphic surface	Soil type[a]	Hydrologic regime[b]
Beach/sand dune	Island/coast beach and shoreline dunes	Co	DT
Tidal flat	Bay and island edges	Cg	MHT
Emergent Estuarine Marsh	Bay edges	Ts	DT
Maritime Forest	Island and low coastal edge ridge-and-swale	Me, Cvc, Rg	OS-SS
Upland Forest	Mainland ridge-and-swale	Sm, Cm, Lab	OS-SS
Freshwater wetland Depressions	Island and Mainland swale depressions	Cvc, Me, Rg	OS

[a] Cg – Capers loamy fine sand, Co – Coastal beaches and dunes, Cvc – Crevasse-Dawhoo complex (Crevasse on ridges and Dawhoo in swales), Cf – Cape Fear loam (swales), Cm -Chipley loamy fine sand (ridges), Lab – Lakeland sand (ridges), Me – Meggett loam (swales), Rg – Rutlege loamy fine sand (swales), Sm – Seewee Complex (ridges), Ts – Tidal marsh, soft.

[b] DT – daily tidal, OS – onsite precipitation and local runoff, MHT – regularly inundated by monthly high tides, OS-SS – onsite precipitation and local runoff and subject to high storm surges.

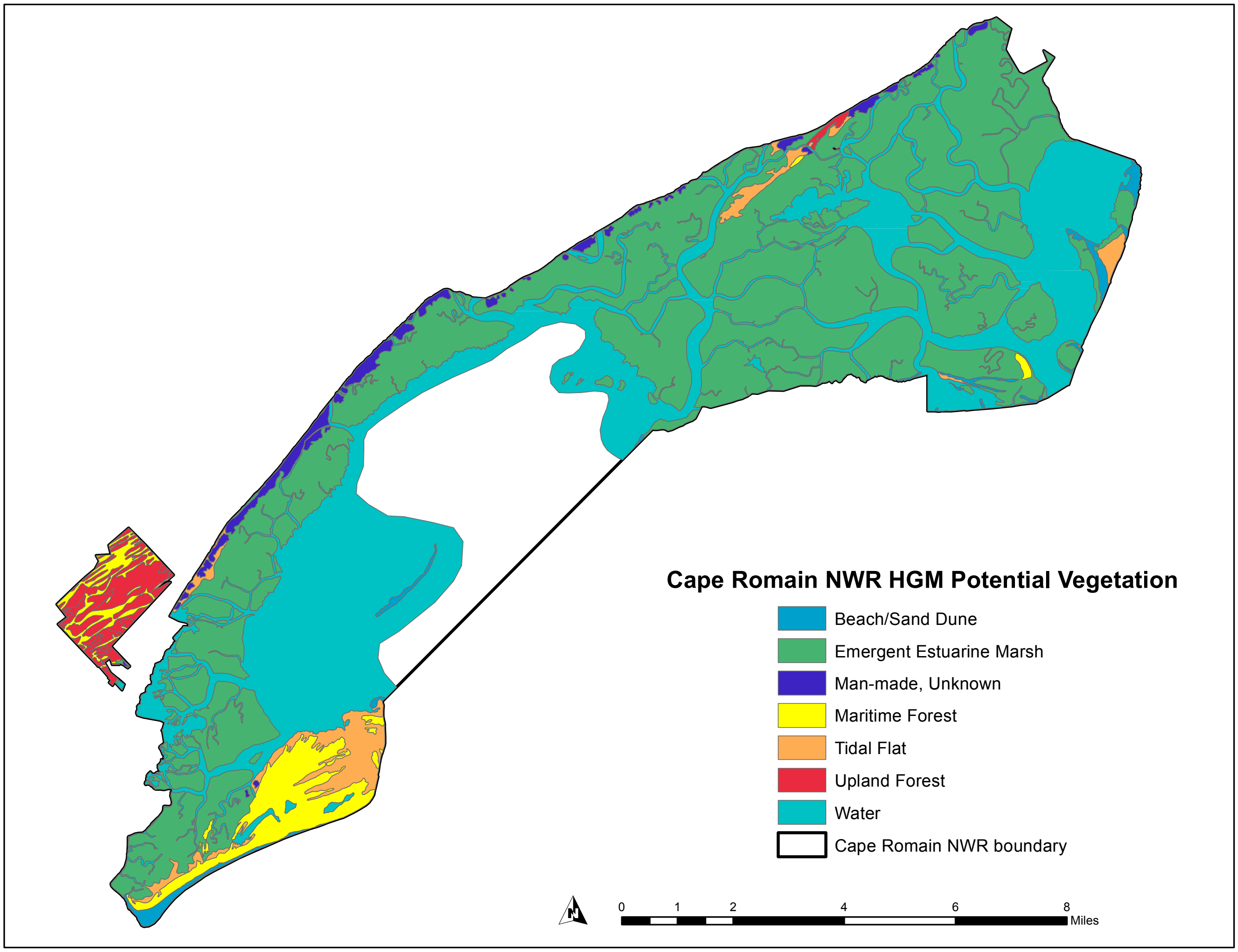


Figure 16. Potential historical pre-settlement vegetation community distribution within the Cape Romain National Wildlife Refuge acquisition boundary based on HGM attribute relationships summarized in Table 5 of this report.

the best predictor of historical vegetation community distribution on Cape Romain NWR and reflects the divergent hydrology of the coastal surfaces and locations (see discussion in the previous paragraphs). The dominant communities of emergent estuarine marsh, beaches and dunes, and maritime forest at Cape Romain NWR occupy distinct HGM settings that reflect coastal hydrology and morphology that grades from the ocean and bays to higher elevation inland (or barrier island) areas. Subdivisions of high vs. low estuarine marsh are more difficult to map because of variable and changing coastline morphology and alterations to fresh water flows and sediments to regional bays and islands since the 1930s. Consequently, we did not attempt to speculate on the precise map boundaries of these marsh sub-types for historic periods other than to distinguish between marsh dominated by emergent vegetation vs. more barren tidal flat surface. Further, inland and barrier island topography has changed substantially from historical periods because of natural and man-made processes including purposeful construction of impoundments on Bulls and Cape Islands and clearing and development on inland areas. This topographic alteration makes it difficult to know the historical extent and distribution of small freshwater wetland depressions in these areas, but several undoubtedly were present, especially in swales in Dawhoo soils. Further, mainland swales with Rutlege, Cape Fear and Meggett soil types also likely contained some freshwater wetland depressions.

Animal communities historically and currently present at Cape Romain NWR are diverse given the existence of many freshwater and brackish-coastal habitat types. These species included numerous waterbirds, landbirds, mammals, amphibian/reptiles, molluscs, and fish species. White-tailed deer (*Odocoileus virginianus*) and red wolf (*Canis lupus rufus*) were noted in early explorer accounts and by native people during the pre-settlement period (USFWS 2010). Waterfowl and waterbirds migrated, nested, and over-wintered in these areas depending on climatic conditions affecting island surface area, salt concentrations, and maritime forests. Many species used the barrier islands present on Cape Romain NWR during the breeding seasons including brown pelicans (*Pelecanus occidentalis*), American oystercatchers, royal terns (*Thalasseus maximus*), black skimmers (*Rynchops niger*), heron species (*Egretta* spp.), and loggerhead turtles. Other important species used a variety of the habitats such as the piping plover, wood stork (*Mycteria americana*), West Indian manatee (*Trichechus manatus*), horseshoe crab (*Limulus polyphemus*), eastern oyster (*Crassostrea virginica*), and clapper rail (*Rallus longirostris*).

Relatively little is known about the herpetofauna at Cape Romain NWR, but about 50 species of amphibians and reptiles have been documented on the refuge (USFWS 2010:26). Cape Island supports the largest nesting population of the southeastern loggerhead sea turtle north of Cape Canaveral, Florida. Recently, nearly 1,500 turtle nests were laid on Cape and Lighthouse islands (USFWS 2010). Diamondback terrapins (*Malaclemys terrapin*) are abundant in the waters adjacent to the refuge and many are suspected to nest on the northern barrier islands. A great diversity of fish and crustacean species are present at Cape Romain NWR such as crabs, shrimp, spottail bass (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), flounder (*Paralichthys* spp.), sheepshead (*Archosargus probatocephalus*), and black drum (*Pogonias cromis*). A complete list of animal species that have been documented at Cape Romain NWR is available in the refuge CCP and refuge species list publications.

Robert Burton

Colin Knight

Raye Nilius

K. King

Steve Hillebrand

"A New Description of Carolina", engraved by Francis Lamb (London, Tho. Basset and Richard Chiswell, 1676) (Note North is oriented right). From Wikimedia Commons.

Cary Aloia

CHANGES TO THE CAPE ROMAIN ECOSYSTEM

SETTLEMENT AND EARLY LAND USE CHANGES

Native people first occupied the South Carolina Atlantic coastal region around 6,000 years before the present (BP). Sea level rises have destroyed most old archaeological sites and the earliest verified locations are approximately 4,000 BP age (Edmounds 1990). These more recent sites are from the Late Archaic and early Woodland periods where people created shellfish mounds or middens throughout the region. Shellfish rings also have been discerned averaging 30 feet in diameter and from 2 to 10 feet high, made of mostly oyster shells. These rings may have been used for a variety of activities (Edmounds 1990). Three main tribes inhabited South Carolina; the Cherokee in the Blue Ridge Mountain region, Catawba in the Piedmont, and the Yemassee who resided in the Lowcountry coming north from Florida and Georgia. The Yemassee fished and hunted, building wigwams covered by palmetto leaves in the winter and mounds as burial sites. The Sewee Tribe inhabited the Lowcountry area, specifically the lower Santee River through the 1600s and into the early 1700s. Some accounts indicate that they may have been the first tribe to deal with early European settlers (USFWS 2010). The Sewee Tribe was decimated by the early-1700s from smallpox and the few survivors apparently then joined the Catawba Tribe to the north.

Christopher Columbus first discovered the Carolina region during one of his voyages to the Americas. De Soto also traveled to this region in 1540 and encountered Native Americans carrying mulberries (Edelson 2007). However, the area was largely unsettled by Europeans until it was named and colonized by French Protestants who landed at the mouth of the Albemarle River where a fort was built. The first English settlements were constructed from 1670-80, and settlement locations changed several times until permanent settlement in the area of the present city of Charleston (Ramsay 1858; Hewat 1836). The revocation of the Edict of Nantes in 1685 by King Louis XIV drove groups of Protestants from France, many of whom settled in the Lowcountry of South Carolina, specifically along the Santee River (Ramsay 1858). Cultural clashes between the Native Americans and Europeans caused many ongoing conflicts which culminated in settlers placing a price on heads of troublesome Indians who were then caught and shipped off to the West Indies as slaves. A Royal Government was formed in 1720 consisting of a governor, assembly, and council modeled after that in Great Britain. Throughout this time forts were built on rivers and islands, including one on Bulls Island to help protect settlers and shipping exports. A treaty was signed in 1755 between Governor Glen and the Cherokee who ceded lands to the King of England to ensure the safety of new settlements. Constant hostilities continued in the region between Britain and Spain with invasions across borders common. Hostilities finally ceased upon the signing of the Treaty of 1763 between Britain, Spain, and France. These two treaties increased the safety of the region, stimulating an influx of large groups of immigrants from Switzerland, Holland, Germany, Ireland, and Scotland who settled in the Lowcountry, laying claim to the most valuable lands of South Carolina. This region served as an asylum for various peoples being persecuted and impoverished. The largest group throughout this time came from Ireland seeking freedom from domestic oppression, finally ending with a surge of immigrants fleeing from revolutionary France.

Agricultural activities began in association with the earliest European settlements (Edgar 1998). Plantations were developed through the draining of swamps and leveling of forests in the Lowcountry, efficiently and effectively altering the entire ecosystem. Hydrology was highly modified creating a consistent regime that prevented the system from effectively buffering changes in climate or from normal processes such as flooding (Edelson 2007). Initially settlers attempted highland grains and corn along the coastal plain; however, these crops were not suited to the coastal sandy soils. Furs and pine-based products (especially turpentine, rosin, and pitch, for ship construction) were the primary early commodities in this region. In 1693, Governor Landgrave Thomas Smith introduced rice to the settlers, which became the main crop supporting the colony. During this period, extensive clearing of coastal swamp lands in estuaries and deltas of major South Carolina coastal rivers within the zone of tidal influence (but above the upper limit of saltwater incursion) occurred. Tidal rice fields were developed with levees and "trunk"-type water-control structures to allow seasonal flooding and drying. These rice field impoundments were flooded with freshwater at high tide during the growing season and drained on falling tides during harvest. Rice exports swelled from 18,000 barrels in 1724 to 106,419 barrels in 1792. Indigo began to be grown in the mid-1700s rising to 1,107,660 lbs. in export but was almost completely replaced by cotton which became the new main export in the late-1700s. Black seed or long staple cotton was the dominant types of cotton grown along the coast. Rice continued to be an important crop with producers expanding to higher ground and swampy areas. Swamps also were drained in order to plant maize which reached its highest export production in 1792 (Ramsay 1858).

Water developments in the Cape Romain NWR region began as early as the late 1600s in the form of wells in the surficial aquifer (Campbell et al. 2011). Further water developments began in 1793 along the Santee River by settlers. The Santee Canal was completed in 1800 and linked the Santee and Cooper Rivers to provide easier access between central portions of South Carolina and the Charleston Harbor (Porcher and Salley 1903); most of the canal now lies beneath Lake Moultrie. Originally authorized by the Rivers and Harbors Act of 1880 (House Report 111-285 2009), portions of the AIWW were constructed after the U.S. Revolution, but was mostly completed in the early-1900's with all but two phases completed by 1947 (http://www.coastalguide.com/south-carolina-intra-coastal-waterway.html). Initially the AIWW was constructed using many natural waterways long the coast of South Carolina, ranging in width from 90 to 100 feet, and approximately 12 feet deep (USACE undated, Faustini et al. 2013) incorporating a 4 mile cut through the Santee Delta (USFWS 2010). The AIWW effectively separates the mainland from the estuary marsh (Fig. 12) on Cape Romain NWR and is a conduit for freshwater discharge from the South Santee River, but it prevents overland and groundwater discharge of freshwater directly to the estuary marshes on the refuge (Faustini et al. 2013). Dredging of the AIWW has occurred along the AIWW at the refuge perimeter within refuge boundaries in specific locations, but not in recent years (Freeland 2012, USFWS refuge annual narratives). Some of the dredged spoil material deposits within refuge boundaries have been mapped as 'made land' on the soil survey (Fig. 8).

From 1939 to 1941, the Santee-Cooper Project built dams to create Lake Marion on the Santee River and Lake Moultrie on the upper Cooper River (Patterson et al. 1996). About 80% of the long-term discharge of the Santee River was diverted into Lake Moultrie. The Santee-Cooper flow diversion eventually increased sedimentation in the Charleston Harbor and subsequently, a 12-mile "Rediversion Canal" with a hydrolelectric dam (St. Stephen Dam) was constructed from Lake Moultrie to the Santee River in 1985 (Hockensmith 2004). The dams and river diversions now regulate freshwater flows and discharges to the estuaries north and south of the refuge and a majority of river sediments from upstream are deposited in Lakes Marion and Moultrie, reducing sediment sources that historically were important for aggradation of barrier islands and beaches (Lennon and Neal 1996, Faustini et al. 2013). Another consequence of the Santee-Cooper Project was an increase in salinity in the Santee Delta because of altered and diminished freshwater flows to the area, although completion of the Rediversion Canal partly restored freshwater flows to the Santee Delta (Faustini et al. 2013:20).

CONTEMPORARY CLIMATIC CHANGES

In the past 100 years temperatures in the ACP have increased by about 1.2 to 1.4^{o} F with the warmest period of increase occurring in the past 20 years. This upward trend in temperature may increase given continued emissions of greenhouse gases (USFWS 2010, Faustini et al. 2013). Changes in the global climate have become apparent in tidal water levels in the South Carolina coastal region. Increases in tide levels accompanied with subsidence of this region may increase the potential for habitat conversion on the Cape Romain NWR. The Intergovernmental Panel on Climate Change (IPCC 2007) and the SLAMM (Warren Pinnacle Consulting 2012) have noted and predicted potential sea levels and potential habitat conversions based on different rates of change. The IPCC estimates a rate of change of 3.15 + 0.25 mm/yr or 1.03 ft in 100 years. The Charleston gage indicates that a similar rate of change (30 cm by 2100) is most likely although some recent work indicates that this estimate is too conservative and more appropriate estimates may be 75 to 190 cm by 2100 (Fig. 17; Faustini et al. 2013). Table 6, prepared by Warren Pinnacle Consulting (2012), shows general habitat change in acres based on potential changes in sea level (Faustini et al. 2013).

CONTEMPORARY HYDROLOGIC AND VEGETATION COMMUNITY CHANGES

Island and Wetland Impoundment Management

Two lighthouses (built in 1827 and 1857 respectively) were in place on Lighthouse Island when the refuge was established in 1932, although the 1827 lighthouse was no longer operational; the 1857 lighthouse remained in operation until 1947 (USFWS 2010). Major land and water alterations have occurred on Bulls Island since the early 20th Century (Faustini et al. 2013:21-22). U.S. Coastal Survey maps for Bulls Island in the mid-1870s indicated that Jacks Creek was a tidal creek surrounded by an open embayment of tidal marsh. On the south end of the island, maps show open, unvegetated, areas (likely agricultural fields) north and south of the current Beach Road near the present day Lower Summerhouse and House ponds. The 1919 U.S. Geological Survey map of Bulls Island also showed the above areas as tidal marsh and two small impoundments were present at the House and Big Pond locations with a narrow connected waterway. In 1925 New York banker Gayer Dominick purchased Bulls Island for a winter residence and hunting area. Dominick built the large "Dominick House" residence shortly after he purchased the island and subsequently constructed some levees and water-control structures to manage wetlands for waterfowl hunting. In 1936, Dominick donated the island to the Cape Romain Migratory Bird Refuge, as it was known at the time. Upon acquisition, managers began developing the infrastructure for waterfowl impoundments on Bulls Island and Cape Island. Ditches were dug and water control structures were installed and

Table 6. Predicted gain (acres) in land cover categories by 2100 under different SLAMM sea level rise scenarios (from Warren Pinnacle Consulting 2012, with initial coverage from 2009 National Wetland Inventory data layer).

Land Cover Category	Initial Coverage (acres)	A1B Mean (0.39 m)	A1B Maximum (0.69 m)	1 m eustatic	1.5 m eustatic	2 m eustatic
Estuarine Open Water	20116	742	1502	2876	19842	30580
Open Ocean	5885	128	138	147	186	274
Tidal Flat	72	796	17270	24184	11266	1500

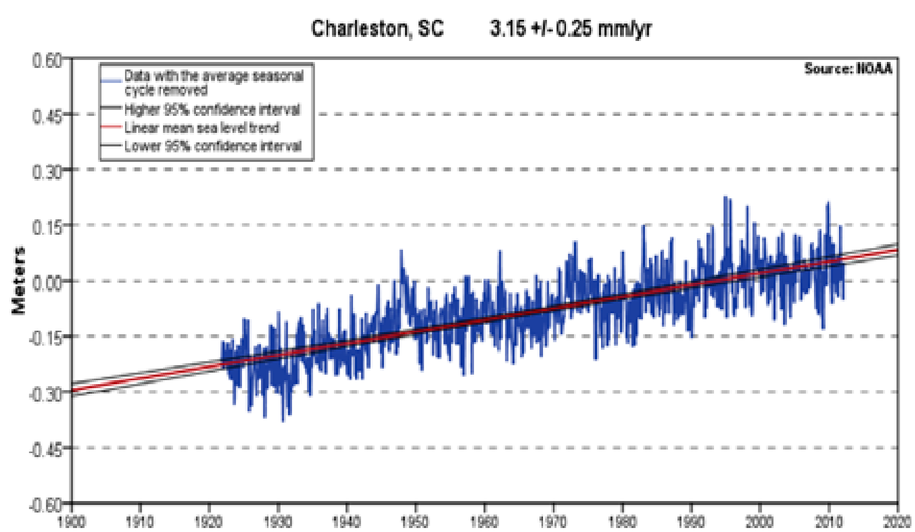


Figure 17. Mean sea level trend at Station 8665530 in Charleston, South Carolina. Data from http://tidesandcurrents.noaa.gov and presented in Faustini et al. 2013. Mean sea level trend is 3.15 mm/year with a 95% confidence interval of +/- 0.25 mm/year based on monthly mean sea level data from 1921-2006.

repaired. Rainwater and runoff provided water for the managed impoundments. From the late 1940s to the late 1960s, the Dominick House was operated as an inn and bed and breakfast for elected officials, conservation organizations, bird watchers, nature visitors, and anglers.

Historically, in the mid-1870s, Jacks Creek on Bull Island was a tidal creek associated with an open tidal embayment of estuarine marsh, subject to tidal flows entering from the north end of the island (see Faustini et al. 2013:21). At that time, the current Moccasin Pond, New Pond, and Pools 1-3 (Fig. 18) were fingers of the Jacks Creek tidal embayment. In 1940 the CCC completed a dike that impounded the Jacks Creek tidal embayment, which created an 800-acre fresh to brackish-water impoundment on Bulls Island. A dike was built by WPA crews on Cape Island to impound 300 acres, in an apparent attempt to create another large fresh-brackish water wetland impoundment (USFWS annual narratives). The Jacks Creek dike along with the dikes that created the Moccasin Pond, New Pond, and Pools 1-3 artificially created a fresh to brackish wetland regime in a former tidal marsh area. The location of these dikes and associated water-control structures in a former tidal creek and next to the ocean made the impoundments subject to continual damage from high tides, tropical storms, and animal disturbances such as alligators burrowing into dikes. By 1948, new and recently restored structures and dikes were failing on the Jack's Creek impoundment, preventing water

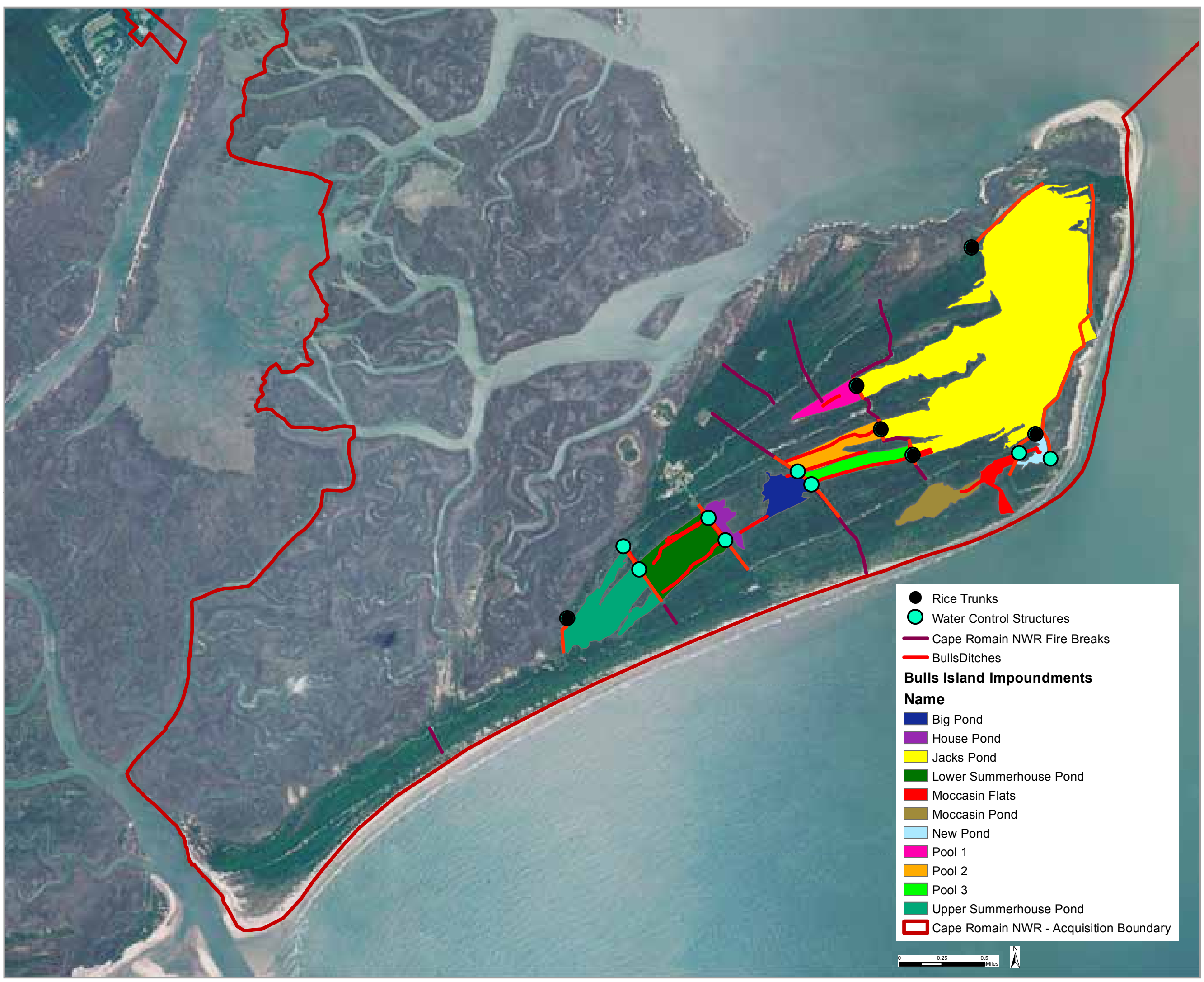


Figure 18. Wetland impoundments and water delivery infrastructure on Bulls Island, Cape Romain National Wildlife Refuge.

level management and storage capacity (USFWS annual narratives, Table 7). Since that time, repairs of impoundment infrastructure havs been needed to maintain the impoundments and the size of the Jacks Creek Impoundment has been reduced to about 485 acres.

Cape Romain NWR currently contains 10 artificial wetland impoundments primarily on Bulls Island that are managed using water delivery infrastructure, including 14 water-control structures and 4 miles of ditches which allow water to flow by gravity through the impoundments (Fig. 18). A history of the dike and water-control features and management of the impoundments is provided in refuge annual narratives (Table 7) and the refuge WRIA (Faustini et al. 2013). These impoundments were constructed across differing soil series and elevations (Figs. 19, 20). A majority of the Jacks Creek impoundment was constructed in a Capers soil type, which historically was a tidal marsh community. Currently the Jack's Creek dike is in danger of being breached as tides have continued to erode the beach up to the toe of the dike in several locations. A new interior dike was built in 1987, and a dike segment was modified in 2008 to prevent loss of the entire unit if encroaching tides breached the exterior dike (USFWS refuge annual narratives, Faustini et al. 2013). The Cape Island dike was breached repeatedly and the impounded area was abandoned after the Class I Wilderness Area was designated in 1975. Management of the impoundments since acquisition has sought to maintain freshwater habitat although onsite precipitation and local runoff is the only water source. In 1946 the manager indicated that he felt water management had previously artificially held water too high over the winter, promoting undesirable plant species such as cattail (USFWS refuge annual narratives). Water was drained from the impoundments in spring and held at approximately four inches deep over as much of the marsh flats as possible. Thereafter, water management on the refuge was changed to increase different preferred rush species through draining many of the impoundments to maintain moist conditions with little standing water (USFWS refuge annual narratives). However, over time, this "drainage" water management philosophy changed and water levels subsequently were managed for more consistently deeper depths throughout the year, although impoundments dried during dry years.

Beach/Dune Erosion

Beach erosion on the barrier islands at Cape Romain NWR has been an ongoing process, noted prior to refuge establishment and ongoing since that time (Table 7, USFWS annual narratives). Sawmills were established on Bulls Island in 1938 to provide onsite lumber for the CCC's construction of groins used to prevent beach erosion (Table 7). The placement of these groins was ineffective over time as coastal erosion and sea level rise occurred (USFWS refuge annual narratives). In the 1960s and 1970s, sand fences were routinely constructed along the beaches on Cape and Bulls Islands to help promote dune growth. Also, several miles of dunes were mechanically pushed up on Cape Island in 1963 with subsequent seeding of ryegrass (Table 7, USFWS refuge annual narratives). Beach erosion on Cape Romain NWR continued with a loss of 15 feet/year documented in the late-1980s culminating in extreme damage from Hurricane Hugo in 1989 to the barrier islands. Major sites of damage included the elimination of many dune systems with an average loss of 75 feet of beach, elimination of Bird Island, leveling of Marsh Island and White Banks, two new high tide inlets cut on Raccoon Key, and overall leveling of the maritime forest including 98% of the old age pines and 50% of the oak forest (USFWS refuge annual narratives). Since that time, barrier islands have continued to erode and build, changing shape as a result of multiple factors including reduced sediment transfer and deposition from the regulated Santee River, accelerated erosion from rising seas, storm events, high tides, wind, and waves. For example, since 1954, Cape Island has decreased in width and in extent to the west but is accreting to the north (Fig. 21). In 1999, Sandy Point was about 75 acres, but by 2009 the island had disappeared (Fig. 22). Cape and Bulls Islands have lost about 20 linear feet of beachfront each year (USFWS 2010:42). Overall loss of surface area on islands since 1875 is 2,105 acres or 19%, with losses increasing after 1950 from 6.3 acres/year to 26.4 acres/year (Faustini et al. 2013). Some future projections suggest that Cape Island is at risk of being inundated and Bulls Island greatly reduced in surface area within the near future.

Recent analyses suggest that tidal creeks on Cape Romain NWR are rapidly incising headward into estuarine marsh areas (Hughes et al. 2009). The rate of incision is about 1.9 m/year and data suggest that tidal incision began about 1940, coincident with the closure

Table 7. Chronology of wetland development and management activities on Cape Romain NWR from 1938 through 2003 (summarized from USFWS refuge unpublished annual narratives).

Year	Location	Development Activities
1938	Jack's Creek Pond	CCC camp completing large dike (Jack's Creek interior dike) to impound 800 ac of water for waterfowl marsh
	Bull's Island	Sawmill established to produce lumber for groynes; Timber groynes used on east and west end to help prevent further beach erosion
	Cape Island	WPA program constructing dike 3/4 mile long to impound 300 ac of freshwater for waterfowl
1940	Summerhouse Pond	Reinforced old dike at south end of pond
1946	Jack's Creek Pond	Repaired sluice
	Bull's Island	Installed four sluices in Summerhouse interior dike, House Pond, Moccasin Pond, and one under the Moccasin Pond R.; allows water to be drained from all of the Bull's Island impoundments to Jack's Creek and into the Bay
	Bull's Island	60 potholes dynamited in Jack's Creek, Upper summerhouse, and Moccasin flat marshes
1947	Summerhouse Pond	Alligator caused a large break in the dike 15' x 4' at low tide; repaired
1948	Upper Summerhouse pond	A trunk was re-installed to expedite draining of the pond
	Cape Island	Brush fence installed to help sand dunes on ocean beach from washing away
1949	Jack's Creek Pond	Structure caved in; no control of pond
	Summerhouse Pond	Installed 14"x4'x48' water control structure
1950	Summerhouse Pond	Trunk removed from dike and reinstalled in the check bank between Lower summerhouse and summerhouse ponds
1951	Jack's Creek Pond	Replaced washed out water control structure
1952	Cape Island	Impoundment drained
1953	Jack's Creek Pond	Gate attached to water control structure
	Cape Island	Blasted 2,500' of ditch to allow pond to be drained 2' lower than previously
	Lower Summerhouse Pond	Installed trunk across Summerhouse Road
1954	Jack's Creek Pond	Water control structure leaking due to alligator hole allowing salinity to increase
	Lower Summerhouse Pond	Blasted 2,000' of ditch to allow pond to be drained
1955	Jack's Creek Pond	Reinforced east side of dike with sand
	House and Lower Summerhouse Ponds	Blasted 1,000' of ditch
1959	Moccasin Pond	Pushed up approximately 2,000' of sand dunes along the ocean side of pond as a temporary control measure; Reinforced 5,000' of dike
1962	Jack's Creek Pond	Constructed sand fence
1963	Jack's Creek Pond	Constructed 1,200' of sand fence; constructed 1/2 mile long dike extension along threatened portion
	Moccasin Pond	Constructed a 3/4 mile long protective dike around lower ocean side
	Bull's Island	Built a road 3.3 miles long from Front Beach Road to the south end and a 0.5 mile road from Dynamite House to Big Pond; bulldozed 0.7 miles of sand dunes along the front beach
	Upper Summerhouse pond	Rebuilt pond dike
	Pools 2 and 3	Completed dikes
	Cape Island	Pushed up approximately 3 miles of sand dunes
1964	Bull's Island	Constructed 1,350' of sand fence; blasted two experimental potholes in marshes
	Upper Summerhouse pond	Trunk installed
1966	Cape Pond	Constructed a 2,500' x 35 x 5 dike across south end; installed new trunk in dike
	House and Lower Summerhouse Pond	Metal trunk installed between the ponds on the beach road
	Bull's Island	Wood duck nest boxes and nest baskets placed around pond
1967	Bull's Island	Dune restoration on front beach; beach disced at low tide however one high tide washed it all away

Continued next page

Table 7, continued. Chronology of wetland development and management activities

Year	Location	Development Activities
1970	Acquisition	The state of South Carolina granted easement to several new islands which had formed in the vacinity of Cape Island to the refuge; public opposition
1971	Cape Island	Structure washed out
1974	Bull's Island	27 new wood duck nest boxes put up
1975	Jack's Creek Pond	Repaired water control structure
	Raccoon Key, Bull's and Cape Islands	Beach erosion; endangering Jack's Creek dike
1978	Bull's Island	Constructed a ring dike 700' east of the island to hold dredge material removed from boat basin; water control structures on all impoundments are inoperable
1979	Upper Summerhouse pond	Wing-wall replaced at water control structure
1980	Bull's Island	Beach eroded to within 100' of Jack's Creek dike
1981	Bull's Island	6 water control structures replaced on the island; 5 were stoplog structures the other one is a screw gate with flap gate, connecting Upper summerhouse pond with a tidal creek
1982	Summerhouse Pond	Water control structure began washing out due to heavy rains; reinforced with 175 sandbags and dirt
1983	Moccasin Pond	Emergency dike started washing away; the flats dike and beach road dike were repaired
	Upper Summerhouse pond	Heavy rains caused erosion around water control structure; reinforced with cement and sandbags
1984	Bull's Island	South end lost most of the primary dune system
	Upper Summerhouse pond	Watercontrol structure continued to erode; 800 sandbags placed on saltwater side
	Jack's Creek Pond	Sandbags used to reinforce water cotnrol structure
1985	Jack's Creek Pond	Beach erosion continues; high tide line less than 50' from dike
1986	Moccasin and Jack's Creek Pond	Dikes breached
	Upper Summerhouse pond	Dike was breached, daily tides flowed in and out until repairs completed
	Cape and Bull's Islands	Beach erosion of 15'
1987	Jack's Creek Pond	Constructing a cross dike/emergency dike in the impoundment; will lose 50 ac of the area
1989	Entire Refuge	Hurricane Hugo caused extreme damage to all impoundments and islands; dune systems eliminated; average loss of 75' along the beach (118 ac); Bird Island no longer exists; Marsh Island and White Banks were leveled; 98% of old age pines were destroyed and 50% of oak forest destroyed
1990	Cape Island	Natural, gradual filling of breach on the island
1991	Upper Summerhouse pond	Dike repaired
	Cape and Bull's Islands	Sand fences constructed to help build dunes
	Jack's Creek Pond	Most of dike repaired
1992	Bull's Island	All dikes repaired; one weak spot in Jack's Creek dike that was filled with thousands of sandbags
	Cape and Bull's Islands	Sand fences constructed to help build dunes
1994	Upper Summerhouse pond	Water control structure washed out
	Cape and Bull's Islands	Beach erosion due to severe storms; sand fences constructed to protect dikes and remaining dunes
	Upper Summerhouse and Jack's Creek Pond	Dikes protected with armed sandbags
1995	Cape Island	Dunes continue to erode; the south end of the island is building and filling a channel between it and Lighthouse Island
1996	Cape Island	Primary dune system leveled; break created in island
1997	Cape Island	Previous break was widened
	Bull's Island	South end continues to grow and move towards Price's Inlet
	Lighthouse Road	Culvert installed

Continued next page

Table 7, continued. Chronology of wetland development and management activities

Year	Location	Development Activities
1998	Cape Island	Break continues to change each year but becomes more distinct
	FB#1	Three culverts installed
1999	New Pond	Water control structure installed (connects southern end to Jack's Creek)
	Pool 1	Water control structure installed (connects the pool and Jack's Creek)
	Lower Summerhouse Pond	Water control structure installed
	Cape Island	Primary dune system leveled; break widened
2000	Cape Island	Sand fencing project to create nesting habitat for turtles
	House Pond and Pool 1	Water control structures installed
2003	Upper Summerhouse pond	Primary water control structure failed

of Wilson Dam on the Santee River. The elevated rate of local sea level rise likely is the primary cause of the headwater incision, with decreased sediment supply from the Santee River after dam closure being a further complicating factor (Hughes et al. 2009).

Contaminants and Control Methods

Pollutants, chemicals, and contamination of air, water, and wildlife in addition to predators have been a concern on Cape Romain NWR since acquisition (USFWS 2010, Faustini et al. 2013). Dichlorodiphenyltrichloroethane (DDT) was initially utilized over a large portion of Bulls Island as a tick repellant in the 1940s. Research was conducted by the U.S. Army regarding its successfulness in reducing the amount of ticks on the island and the amount observed on white-tailed deer. Refuge staff were interested in reducing the concentration of ticks on the island as they thought the ticks were having an adverse effect on the white-tailed deer and turkey populations (Table 7, USFWS refuge annual narratives). However, over time, DDT was found to be a main cause in the decline of bird populations and the use of DDT stopped. Throughout the history of the refuge many different types of predator controls were applied, from shooting owls to trapping and poisoning raccoons to prevent turtle nest predation. Rodenticides were utilized for a time in the 1960s to help reduce raccoon populations and although successful, the strategy was discontinued (USFWS refuge annual narratives).

Air Quality Monitoring

Air quality monitoring began in 1978 with the designation of the Class I Wilderness Area on the refuge. Photographic air quality monitoring was initiated and a study completed in 1981 related to potential impacts from the Alumex Corporation aluminum reduction plant, which determined the plant would not negatively impact wildlife despite proposed future increases in sulfur dioxide outputs. An air monitoring station was constructed on the refuge in 1983 with further studies conducted to determine if the aforementioned study was accurate in relation to the effect of increases in sulfur dioxide (USFWS annual narratives, Table 7). After Hurricane Hugo, many new studies were initiated including some to evaluate ozone depletion impacts on vegetation. In 2004 the refuge became one of 70 sites monitored in the US and Canada as part of the Mercury Deposition Network measuring total mercury in wet depositions (Table 7, USFWS refuge annual narratives).

Water Quality Monitoring

In 2001, NOAA began sampling water quality on the Cape Romain NWR, establishing a permanent monitoring site within refuge boundaries. Currently there are 17 creeks in the Cape Romain area that are listed as impaired for a variety of reasons including turbidity, copper, and total ammonia in addition to fecal coliform (Faustini et al. 2013).

Salinity tests have been taken in several impoundments including Jack's Creek since the 1940s to help document changes over time and inform management. Determination of water "quality" based on salinity can be conflicted as species use of, and adaptations to, salinity levels and fresh to saline systems varies. For example, oyster reefs within the AIWW may be negatively impacted by freshwater inputs, however, the Santee River Delta area was historically an important site for many waterfowl, and some shore-and wading-bird species that depend on the availability of freshwater habitats in this area (USFWS refuge annual narratives). As groundwater pumping has increased throughout the Lowcountry region, intrusion of saltwater into freshwater aquifers has become more of a concern.

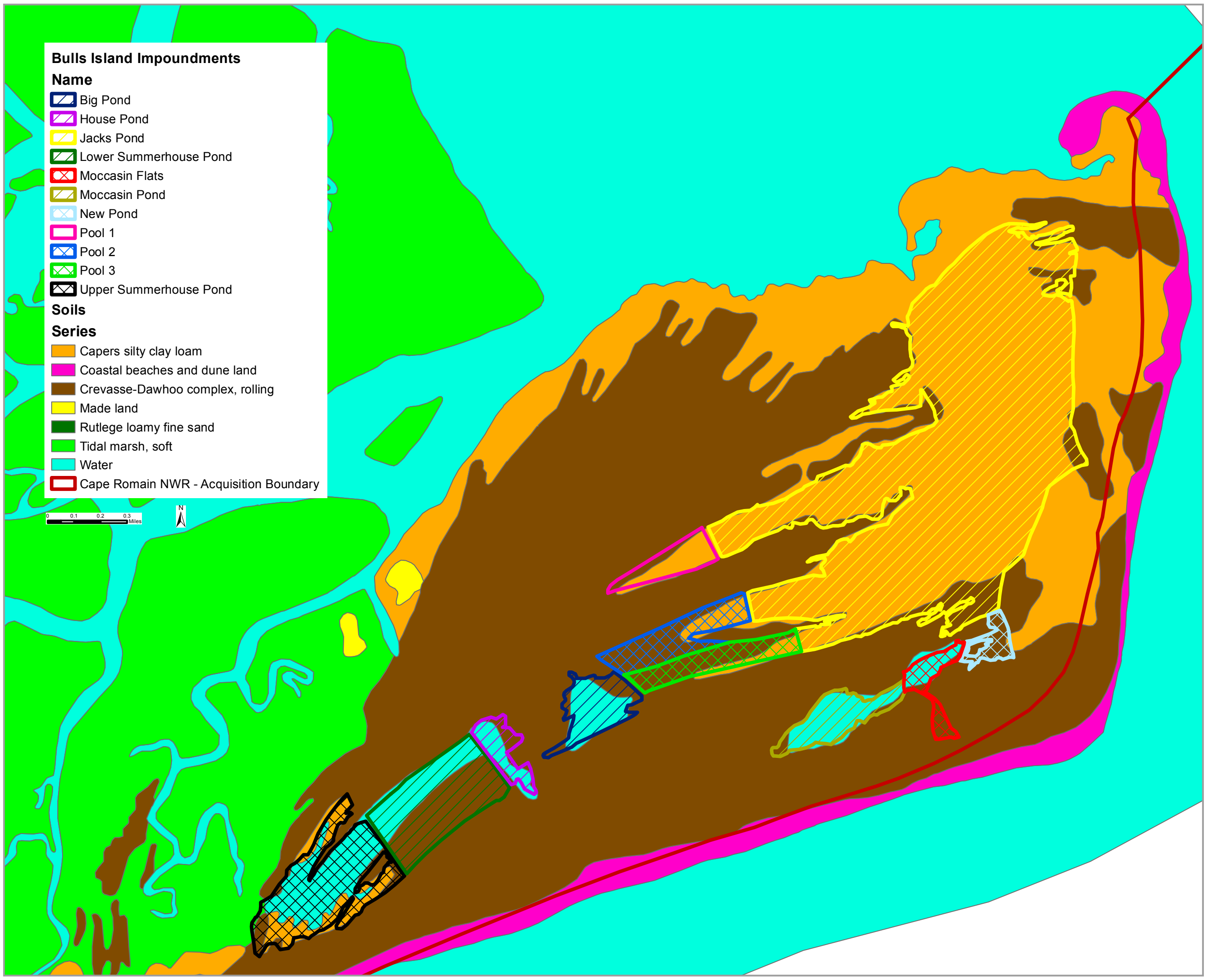


Figure 19. Bulls Island impoundments and water delivery infrastructure in relation to soils on Cape Romain National Wildlife Refuge.

Saltwater began intruding into the Floridan aquifer in the mid-1900s resulting in the region being designated as a groundwater Capacity Use Area (CUA) in South Carolina. Many CUAs have been designated throughout North and South Carolina in order to manage declining groundwater resources. Groundwater use is permitted and monitored through these CUAs in both states. Large cones of depression have been documented throughout South Carolina with some occurring in Charleston in the lower Cretaceous aquifers (Campbell et al. 2011).

Habitat Management

Habitat management on Cape Romain NWR has included physical manipulation of vegetation using logging, burning, mowing, disking, and chemical treatments primarily on Bulls Island. Active habitat management on other areas of the refuge has been limited. The 29,000 acre Wilderness Area, which encompasses almost all of the estuarine tidal marsh on the refuge, was established in 1975 and The Wilderness Act of 1964 prohibits physical developments and most active management on the area (http://www.wilderness.net/NWPS/wildView?WID=96&tab=Area Management). Essentially, the refuge uses "Leave No Trace Techniques" with management mainly directed at providing closed, undisturbed areas, for nesting seabirds, shorebirds, and turtles. Even prior to the establishment of the Wilderness Area in 1975, physical developments and water/vegetation manipulation by the refuge in this marsh area

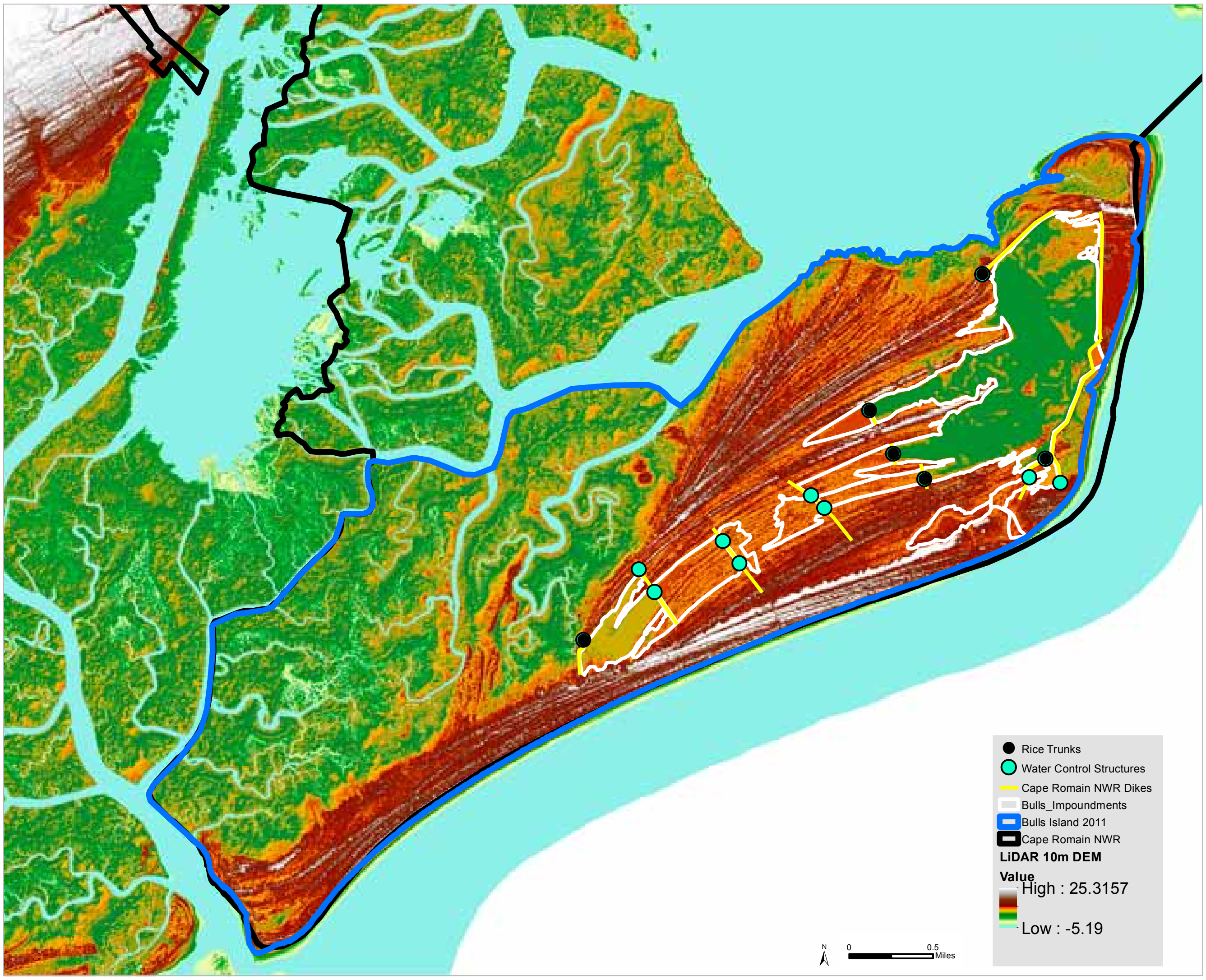


Figure 20. Wetland impoundments on Bulls Island in relationship to LiDAR 10 ft. elevation (data from refuge files).

was limited because of its physical nature and the inability to control water and sediment processes. Fires were purposefully set in some marsh areas, but with the exception of higher elevation areas, the effects of burning were limited on removing vegetation and subsequent effects on vegetation community structure were varied and eventually discontinued (USFWS refuge annual narratives). In the early 1940s, a dike was constructed to impound a ca. 300-acre area on Cape Island, but the levee was soon breached and eroded by wind and wave action and was never repaired or rebuilt.

Fire breaks were established throughout the island and annually planted with a variety of forage species for turkeys and deer, including chufa (*Cyperus esculentus*), rice, winter rye, winter peas, and Lespedeza spp. Some fire was utilized throughout the history of the refuge; however, this type of strategy was sporadic in the maritime forest and had varied results in cordgrass marshes (USFWS refuge annual narratives). Vegetation in the Bulls Island freshwater impoundments consisted primarily of bulrushes (*Schoenoplectus* spp.), widgeon grass (*Ruppia maritima*), banana waterlily (*Nymphaea mexicana*), sago pondweed (*Potamogeton pectinatus*), bushy pondweed (*Najas gracillima*), smartweeds (*Polygonum* spp.), and wild millet (*Echinocloa muricata*). By the 1940s, the refuge staff was trying to control monotypic stands of cattail in most of the impoundments through mowing, cutting, and disking combined with planting/seeding and herbicide applications. Good results in relation to other species were noted within the year of application but overall control

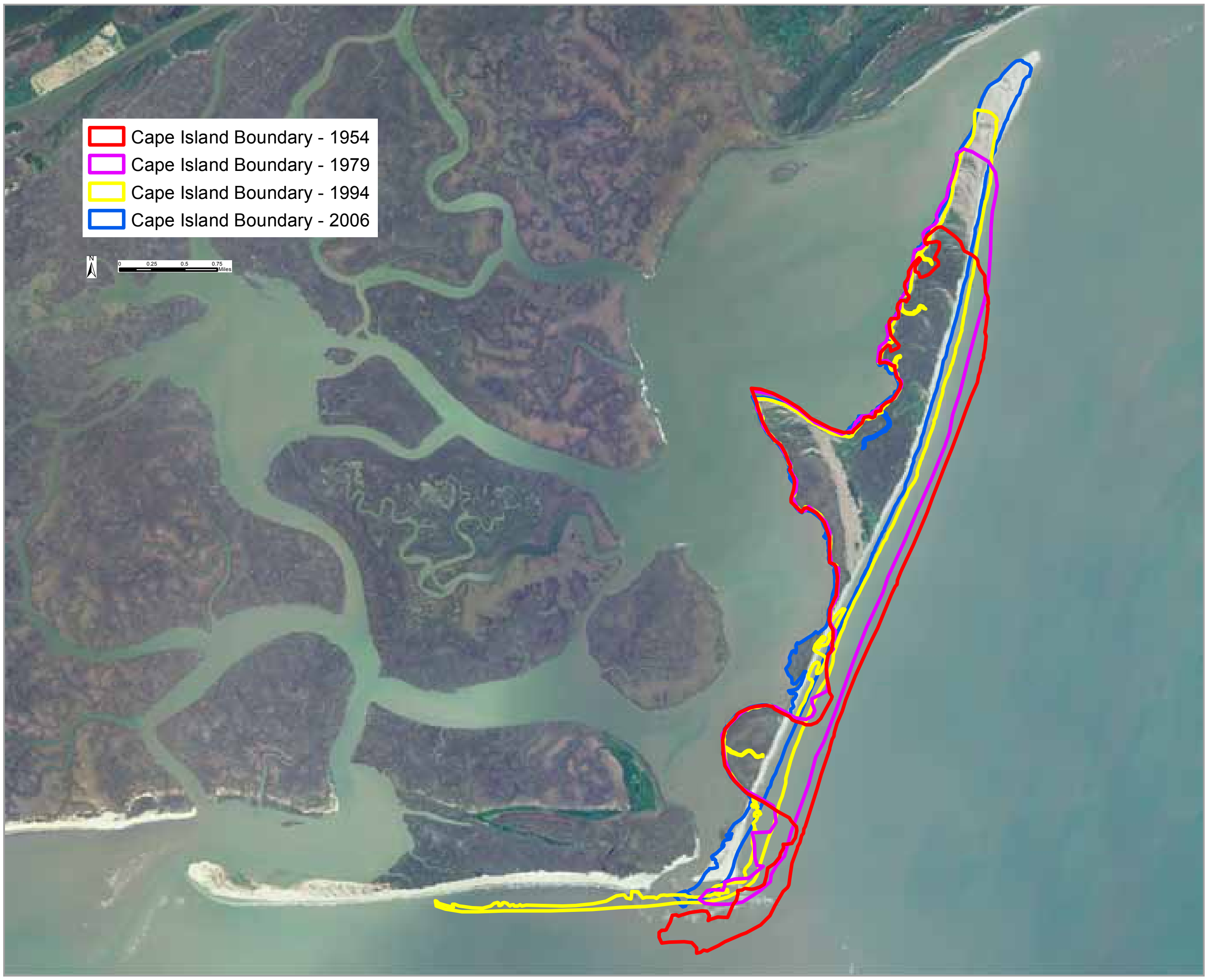


Figure 21. Sequential erosion and accretion of Cape Island from 1954 to 2006 at Cape Romain National Wildlife Refuge (provided by Dan Ashworth, Cape Romain NWR).

of the cattail across years did not occur. During the mid-1950s many of the impoundments began to grow different types of algae which prevented the growth of submergent and emergent plants. Algal blooms increased with higher salinities sometimes caused by saltwater intrusion into the impoundments. Control of cattail and algal blooms continued to dominate staff time through the 1980s. In 1988 Moccasin Pond was managed as a moist-soil area producing many native species of grasses and smartweeds.

The Category 4 Hurricane Hugo in 1989 greatly impacted much of the maritime forests on Bulls Island and throughout mainland areas, including widespread damage on the Francis Marion National Forest. Shortly after Hugo's devastation, Chinese tallow (*Sapium sebiferum*) began invading the former maritime forest areas and the sites became more vulnerable to fires because of the increased heavy downed forest fuel load. In 1993, approximately 11,000 tallow trees were treated or pulled by hand on Bulls Island and efforts to remove and control the establishment of tallow have continued over time. Subsequent regeneration of pine and hardwood saplings on mainland locations became more susceptible to southern pine beetle attacks. At Francis Marion, infested trees have been regularly harvested and salvage sales and biomass thinning has occurred. Other invasive plants, such as Phragmites, Sesbania, and saltcedar (*Tamarix pentandra*), also have expanded on Cape Romain NWR, including many

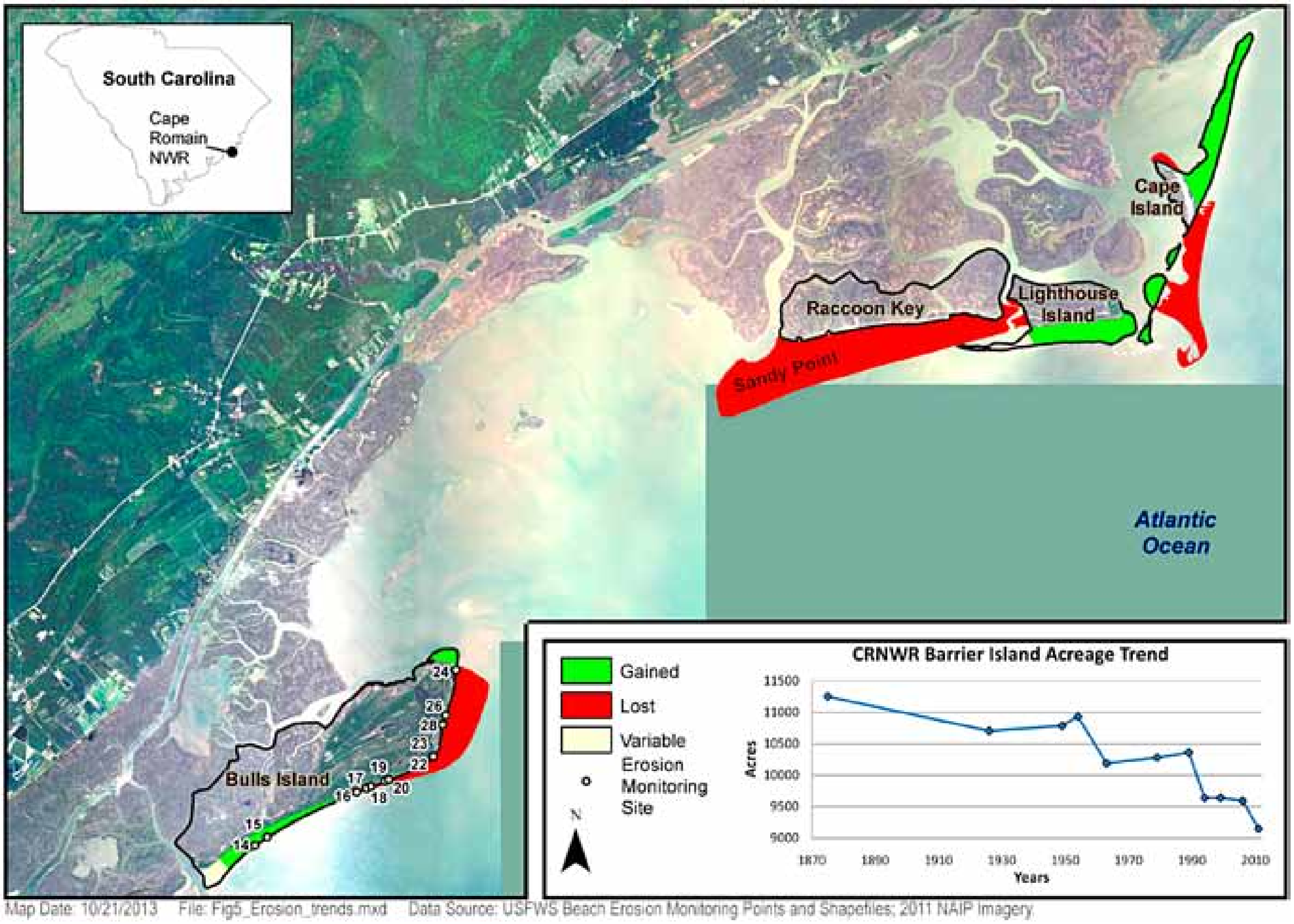


Figure 22. Net erosion and deposition on barrier islands at Cape Romain National Wildlife Refuge, 1875 to 2011. Numbered points on Bulls Island show locations of 2010-2012 ground-based erosion measurements taken by Cape Romain National Wildlife Refuge staff (from Faustini et al. 2013).

impoundments and forest areas (USFWS refuge annual narratives). All invasive species have been treated with various strategies to prevent further expansion.

Vegetation communities on Cape Romain NWR have been modified by humans, beginning with native people who hunted, fished, and participated in some subsidence farming. Hydrologic regimes have been modified and much of the maritime forest has been destroyed through agriculture and urban expansion as referenced previously. In addition, many wetlands have been significantly altered from their historical state. The existing USFWS National Wetland Inventory (NWI) map indicates that a large majority of the refuge is comprised of estuarine and marine wetland with some freshwater forested/shrub and freshwater emergent wetlands. Because NWI data for Cape Romain NWR was found to be inaccurate, refuge staff reclassified habitat types within the refuge acquisition boundary using the Cowardin Classification System (Cowardin et al. 1979). This reclassification identified the following wetland types and acres of those wetland types within the refuge by percentage: Estuarine and Marine Wetlands 48.39%; Estuarine and Marine Deepwater Aquatic Wetlands 44.70%; Upland or Unclassified Wetlands 4.94%; Freshwater Forested/Shrub Wetlands 1.73%; and Freshwater Emergent Wetlands 0.24%.

These values differ slightly from those derived from NWI data, with the most significant differences occurring on Bull Island and the other barrier islands, where NWI does not accurately represent managed wetland impoundments or reflect recent changes in the shape and extent of these dynamic landforms. The NWI mapped Bulls Island impoundments as freshwater wetlands

(Faustini et al. 2013). The National Land Cover Database describes the estuarine and marine wetlands as emergent herbaceous wetlands with Bulls Island impoundments dominated by woody wetlands and evergreen forest along with emergent herbaceous wetlands (Fig. 23). Charleston County also has mapped the area, providing different names to various wetlands and habitats, although the extent of each is similar (Fig. 24).

Wetland loss and habitat conversion has been further exacerbated throughout the Lowcountry because of the large increase in urbanization. From 1990 to 2000, this area saw an almost 15% increase in population, with the same expected to occur in the next 15 years. Expansion of groundwater use, changes in climate, and future urban development will continue to impact these coastal wetlands. Detailed contemporary maps of vegetation distribution and composition on Cape Romain NWR are not available, but some vegetation surveys and mapping is anticipated in the near future.

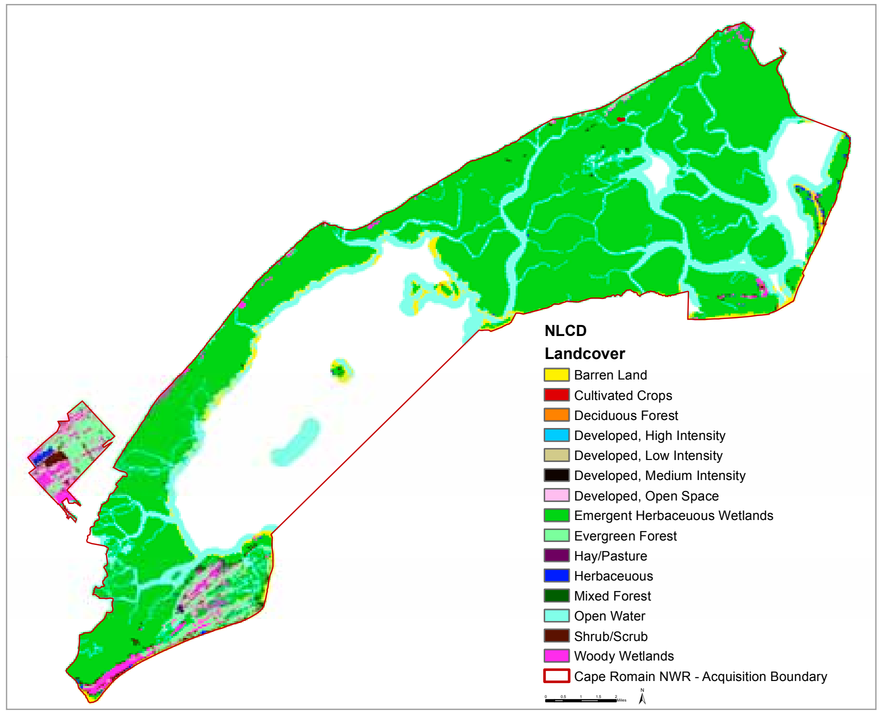


Figure 23. Landcover types taken from National Land Cover database on the Cape Romain National Wildlife Refuge (http://datagateway.nrcs.usda.gov).

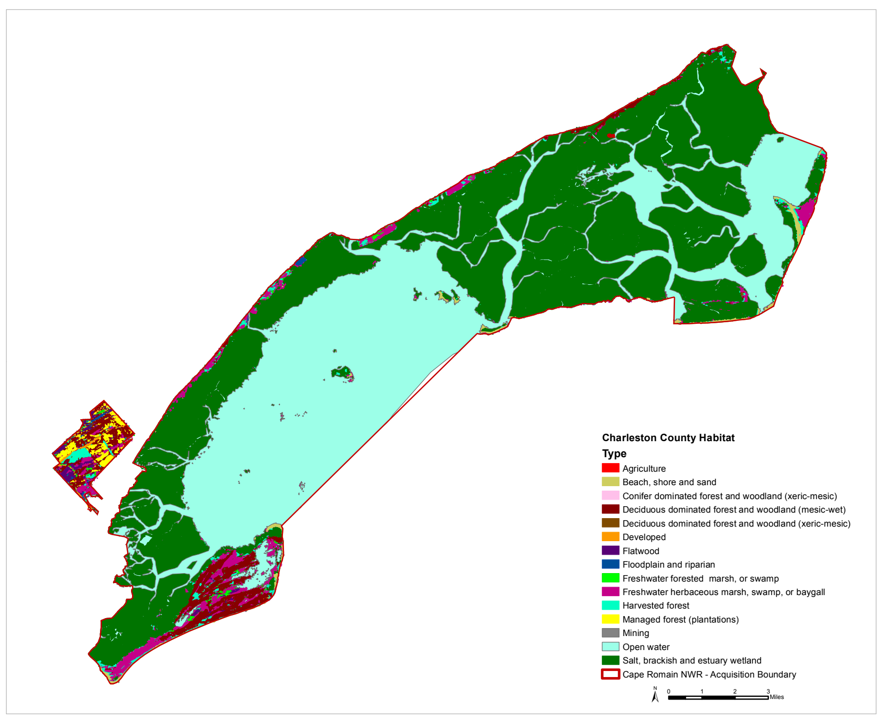


Figure 24. Habitat classifications on Cape Romain National Wildlife Refuge (from Charleston County, South Carolina GIS data provided by Cape Romain National Wildlife Refuge staff).

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OPTIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

Information in this HGM report, the refuge CCP and WRIA (USFWS 2010, Faustini et al. 2013), and other regional publications (e.g., Harper 1911, Bratton 1985, Nelson 1986, Bellis and Keough 1995) have helped describe the historical ecosystem structure and processes in the Cape Romain NWR region and identified the changes to this ecosystem over time, both before and after refuge establishment. Cape Romain NWR complex truly is an ecological "gem" of the South Atlantic Coastal system, and it protects and provides critical resources that help support populations of many species associated with this ecosystem, including several threatened and endangered species such as sea turtles, piping plover, red knot, and seabeach amaranth, along with concentrations of waterfowl, shorebirds, wading birds, raptors, and bay fishes. Generally, vegetation community and coastal habitat structure and distribution on Cape Romain NWR have not changed substantially from pre-refuge conditions, except for alterations to the community structure of maritime forest, and conversion of former tidal marsh habitats to freshwater impoundments, on Bulls Island. Further, active habitat management or ecosystem restoration has not been extensive on the refuge, with the exception of Bulls Island, and the management strategy for the refuge historically has been, and currently is, directed more to protection and passive management than to intensive on-site habitat manipulations. The passive management approach has occurred in large part because of the designation of the large Class I Wilderness Area on the refuge, which prohibits significant physical manipulations of water or vegetation. In effect, the future of habitats and resources on Cape Romain NWR will largely be determined by off-site regional and even continental issues that affect water and sediment inputs, contaminants, disturbances, and sea level rise in the ACP. As such, the utility of this HGM evaluation is largely to reaffirm the issues and directions of the refuge CCP that identifies the larger landscape-scale issues and to suggest options for more active management and restoration on the parts of the refuge where such management can occur, i.e. the non-Wilderness Area, specifically Bulls Island. Additionally, the HGM information for the refuge suggests the ecological attributes that are associated with various communities, and provides direction for future identification of mainland sites where habitats that may eventually change or be destroyed by sea level rise can be restored or protected. For example, if the USFWS or other conservation entities seek more freshwater wetlands in the future, certain mainland soils and geomorphic settings may offer that potential and could be identified for subsequent refuge expansion or protection/restoration.

Annual freshwater inputs into the Cape Romain NWR ecosystem along with sediment transport and deposition from interior rivers and streams historically were important factors that influenced the dynamic distribution and maintenance of estuarine marsh and tidal creek habitat and wildlife populations along with the surface area and topography of barrier islands throughout the area. Surface freshwater inputs to the Cape Romain region were seasonally and annually dynamic, which influenced local and regional fresh and saltwater concentrations and spatial gradients of saline to fresh habitats. Construction of dams and other water development infrastructure on inland rivers and creeks, along with construction and maintenance of the AIWW have altered the hydrology and geomorphic processes in the Cape Romain NWR region. Physical and ecological changes caused by these developments will be difficult to reverse or mediate. In addition to inland and coastal water influences, tropical storms were common in the Southern ACP and produced heavy precipitation events, strong winds, and storm surges that were important ecological "drivers" of the Cape Romain NWR ecosystem. Tides and wave actions associated with these storms helped re-shape the topography of barrier islands and often inundated many areas and flattened dunes that sometimes caused the complete loss of entire bird and turtle nesting colonies. Consequently, annual variation in precipitation, tides, and storms likely caused significant annual variation in amount and distribution of surface water resources, site-specific salinity, available beach and shoreline, and the availability of fresh to tidally influenced wetland habitats.

From the initial establishment of Cape Romain NWR, a fundamental goal of USFWS acquisition and management has been the protection of the ecological integrity of the regional South Atlantic coastal ecosystem along with the provision of key resources to the unique, rich biodiversity, and often imperiled flora and fauna of the region. This overarching conservation goal remains preeminent today and for over 80 years of USFWS stewardship has sought to protect the regional landscape and its resources amidst climate, land and water use, and social-political-economic changes. The recent CCP for Cape Romain NWR used hydrogeomorphic information (including soil, geology, and hydrology data) to develop habitat goals, objectives and strategies. The CCP provides important guiding principles, USFWS policy and purpose, and recognition of applied ecological understanding in ultimately stating the objectives. This HGM report expands contemporary understanding about the types, distribution, and ecological processes of historical communities in the Cape Romain NWR region, and by-and-large affirms the directions and recommendations of the CCP, which are heavily focused on long-term protection of the diversity and ecological processes of the system. Specifically, the CCP and the HGM evaluation both suggest: 1) the long-term protection and management of Cape Romain NWR will require vigilance to, and USFWS participation in, larger landscape-scale conservation efforts related to mediating or reducing the long-term detrimental effects of systemic influences of regional land and water use, climate change, and sea level rise; 2) restoration on refuge lands to former communities is potentially possible in some areas and should seek to restore pre-settlement native habitats/communities where possible and appropriate; and 3) active management will be needed to sustain native community integrity and inherent ecological processes in many areas, such as maintaining or replacing maritime forests and the small, but critically important, freshwater wetland habitats on barrier islands.

Primary ecosystem changes in Cape Romain NWR region that must be considered in future ecosystem conservation decisions have been: 1) alterations to the local and regional distribution, chronology, and abundance of fresh and salt surface water; 2) changes in sediment load, quality, and distribution in coastal rivers and bays and offshore transgressive deposition of sediments in estuarine marshes and on islands; 3) increased rate and extent of erosion on barrier islands; 4) development and maintenance of the AIWW; 5) increased continental and regional temperatures and accelerated sea level rise; and 6) invasion of exotic plants on barrier islands and the mainland tracts. As one example of an important landscape-scale issue for Cape Romain NWR, the continued presence of the Santee River Dam currently prevents historical rates of freshwater and sediment transport and input to Bulls Bay, which affects salinity levels in estuarine marshes, marsh sediment replenishment and building, and deposition rates on the islands that surround the bay. The decreased sediment transport to the Cape Romain coastline from the Santee River is especially detrimental as the continual supply of sand historically helped maintain the ecologically critical barrier island size and configuration (Hayes and Michel 2008). Bulls Island is one part of Cape Romain NWR where active habitat management and community restoration has occurred in the past, and that represents opportunities in the future. Here, a major decision about future management should first determine if the artificial wetland impoundments on Bulls Island should/can be maintained and how natural barrier island aggradation and local water regimes and flow pathways can be restored/managed to assist efforts to restore and provide critical habitats and communities.

Past attempts to plan physical developments and active habitat/community management of the refuge largely have been designed to sustain and restore maritime forest areas and to provide fresh to brackish water wetland impoundments for waterbird habitat. Consequently, future management of maritime forests and freshwater impoundments must consider how, and if, they are contributing to desired objectives of restoring native communities and their processes on the refuge. Additionally, future management (including expansion) of the refuge must seek to define the role of the refuge lands in a larger landscape-scale conservation and restoration strategy for the South Carolina coastal region.

GENERAL RECOMMENDATIONS

This hydrogeomorphic (HGM) evaluation study is an attempt to evaluate restoration and management options that can ultimately help protect, restore, and sustain natural ecosystem processes, functions, and values on Cape Romain NWR proper. This study is limited in scope to refuge specific management and does not address pubic uses of the refuge (i.e. consumptive uses), or when and if these sometimes competing uses can be accommodated, managed, or mitigated.

Fortunately, much of the historical Cape Romain NWR community type and distribution remain mostly intact and a primary goal for the future of the refuge is to protect the ecosystem character and its driving ecological processes where possible. As previously stated, and expanded on below, most of the landscape issues that affect the long-term character of the refuge are off-site and reflect large systemic land, water, climate, and sea level rise changes. As such, this HGM report reaffirms the need to understand the potential effects of these larger issues and encourage the USFWS to participate in, and develop strategies for, conservation efforts and programs to address and mediate the potential changes. Managers should pay close attention to several impending future ecosystem changes, some of which are far beyond the scope of USFWS control and the ability of this report to make suggestions about changes (e.g., climate change and sea level rise). At a more local, on site refuge level, ultimately, management of natural vegetation community types and their inherent resources will require changes that help restore (to the extent possible) natural disturbance regimes, the hydrological flow pattern, timing and distribution of water management, and invasive plant management. Despite the probability of future ecosystem changes, Cape Romain NWR can continue to provide key resources to meet annual life cycle requirements for many plants and animals in the South Atlantic coastal region along with providing opportunities for consumptive and non-consumptive wildlife-dependent uses.

This HGM evaluation provides information to support The National Wildlife Refuge System Improvement Act of 1997, which seeks to ensure that the biological integrity, diversity, and environmental health of the system are maintained (USFWS 1999, Meretsky et al. 2006, Paveglio and Taylor 2010). Administrative policy that guides NWR goals includes mandates for: 1) comprehensive documentation of ecosystem attributes associated with biodiversity conservation, 2) assessment of each refuge's importance across landscape scales, and 3) recognition that restoration of historical processes is critical to achieve goals (Meretsky et al. 2006). Most CCP's completed for NWR's to date, including the Cape Romain NWR 2010 CCP, have highlighted ecological restoration as an objective. Generally, historical conditions (those prior to substantial human related changes to the landscape) are considered the benchmark condition to guide restoration efforts (USFWS 2001, Meretsky et al. 2006). General USFWS policy, under the Improvement Act of 1997, directs managers to assess not only historical conditions, but also "opportunities and limitations to maintaining and restoring" such conditions. Furthermore, USFWS guidance documents for NWR management "favor management that restores or mimics natural ecosystem processes or functions to achieve refuge purpose(s)" (USFWS 2001, and see discussion in the refuge CCP).

Given the above USFWS policies and mandates for management of NWR's, the HGM-approach used in this study can inform decisions about future management of Cape Romain NWR, at least where some restoration of historical communities and ecological processes is desired and possible. The HGM approach objectively seeks to understand: 1) how this ecosystem was created and its ecological character or form, 2) the fundamental physical and biological processes that historically "drove" and "sustained" the structure and functions of the system and its communities, and 3) what changes have occurred that have caused degradations and that might be reversed and restored to historic and functional conditions within a "new desired" environment. This HGM approach also helps understand restoration opportunities for the Cape Romain NWR within the context of appropriate regional and continental landscapes, and helps identify its "role" in meeting larger conservation goals and needs at different geographical scales. In many cases, restoration of functional ecosystems on NWR lands can help an individual refuge serve as a "core" of critical, sometimes limiting, resources that can complement and encourage restoration and management on adjacent and regional private and public lands.

HGM evaluations are not species-based, but rather seek to identify options to restore and maintain system-based processes, communities, and resources that ultimately will help support local and regional populations of endemic species, both plant and animal, and other ecosystem functions, values, and services. Management of specific land parcels and refuge tracts should identify key resources used and needed by native species, and support special needs for species of concern such as was done in the Cape Romain NWR CCP (USFWS 2010). This is certainly true at Cape Romain NWR where many threatened and endangered species occur, and are part of the purposes for the refuge. The development of specific management strategies for Cape Romain NWR requires an understanding of the historic context of the regional coastal area relative to what communities naturally occurred there, the seasonal and interannual dynamics and thus availability of community resources, and when and where (or if) species of concern actually were present on the tract and what resources they used. This approach is consistent with recent recommendations to manage the NWR system to improve the ecological integrity and biodiversity of landscapes in which they sit (Fischman and Adamcik 2011). Obviously, some systems are so highly disrupted that all natural processes and communities/resources cannot be restored, and key resources needed by some species may need to be replaced or provided by another similar habitat or resource. Fortunately, Cape Romain NWR largely retains the historical types and distribution of native communities, with a primary focus on protection rather than extensive restoration. Further, the Wilderness designation for the majority of estuarine marsh within the Refuge requires that a strategy of protection, rather than an active management strategy be employed.

Cape Romain NWR is, and will continue to be, highly affected by the significant alterations to local and regional land and water resources and uses. The impetus for establishing Cape Romain NWR was to protect parts of the regional coastal ecosystem and to provide habitats and resources to support populations of many species including waterfowl and waterbirds and threatened and endangered species such as sea turtles and shorebirds. Future management of Cape Romain NWR should attempt to sustain and restore historical hydrologic patterns across the coastal setting, protect and restore native vegetation communities, and to actively manage habitats where possible and needed to provide resources used and required by native animal species. Given this management context, and based on the HGM context of information obtained and analyzed in this study, we believe that future management of Cape Romain NWR should seek to:

1. Maintain and restore the physical and hydrological character of the regional South Atlantic coastal ecosystem.

2. Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes where possible and encourage management strategies that can emulate natural disturbance event processes and frequency including fire, flooding and drought, herbivory, and wind/wave action and that can provide critical resources to key fish and wildlife species.

The following general recommendations are suggested to meet these ecosystem restoration and management goals for Cape Romain NWR.

1. Maintain and restore the physical and hydrological character of the regional South Atlantic coastal environment and ecosystem.

The ecology of the South Atlantic coastal ecosystem at Cape Romain NWR is based on the unique physical setting provided by the protective barrier islands and the connectivity of Atlantic Ocean water to bays, freshwater inputs from inland rivers, and continuity and connectivity of tidal waters throughout the region. The geographical merging of mainland uplands, rivers and creeks, coastal shores and estuarine marshes, open water bays, and islands form the hydrogeomorphic attributes that support the many vegetation communities in the region. The rich community diversity and juxtaposition creates complex, highly integrated, and productive food webs and energy flow pathways in this ecosystem. These diverse resources are used by many animals including resident, winter, and migratory species found in inland, estuarine, coastal, and marine systems. The presence of several threatened, endangered, and species of concern at Cape Romain NWR attests to the unique historical and current biological diversity and productivity of the region.

Given the integrated physical and ecological context of the coastal system at Cape Romain NWR, future conservation actions should first seek to protect the physical and hydrological character of regional watershed and coastal lands and waters in as natural a state as possible and then secondly remediate or restore altered features if possible. Further, vigilance must occur to guard against future detrimental changes and to deter them if possible. Obviously, addressing larger systemic issues for the South Atlantic Coast will require attention, support, and action from many entities, of which the USFWS is only one agency. Also, certain changes to the local environment are caused by factors outside of the region, such as global climate change and sea level rise. Where some future changes can be expected, and probably not completely deterred or delayed, management and conservation action should attempt to anticipate the projected future changes and understand opportunities and challenges for current conservation lands and resources – and begin to develop strategies to provide resources on these and other lands in the future. Addressing these larger environmental issues extends far beyond the scope of this HGM and ultimately must deal with climate change, sea level rise, water use and distribution, and coastal and mainland uses. Each of these issues is large, complex, and likely will ultimately require policy and legislative mandates.

Future conservation planning at Cape Romain NWR should accept the challenge of protecting and managing USFWS lands within the larger landscape context of the South Atlantic Coast. This planning will require cooperation and collaboration with many partners. In some cases, specific actions on refuge lands can help provide key resources or attributes that contribute to the larger ecosystem/landscape goals (e.g., providing freshwater wetlands on barrier islands, which now is destroyed in most coastal areas), while in other cases the USFWS should participate in regional efforts to address systemic issues such as fresh water flows into bays, protection of the barrier islands, prevention of bay and coastal marsh contamination, and continued enforcement of closed areas and resource use restrictions for trust resources and species of concern.

Currently, Cape Romain NWR lands are almost entirely east of the AIWW and 90% of refuge lands are below 5 feet amsl. This low-lying complex is therefore highly susceptible to continued sea level rise along with rapidly increasing coastal and barrier island erosion and development. While some direct management intervention may be possible in the short term to protect and provide the historically critical habitats of beaches, maritime forest, estuarine marsh, and interior freshwater wetlands, the long term conservation and provision of resources in the region will require expansion of conservation lands inland where sea level rise will ultimately change the regional ecosystem. The refuge CCP has identified a potential focus area for further land protection/management and expansion of Cape Romain NWR between Highway 17 and the AIWW. Ultimately acquiring and protecting this area would help connect existing habitats (such as between Francis Marion National Forest and the refuge) and help compensate for future anticipated loss of current coastal and barrier island habitats including the limited and imperiled freshwater wetland, maritime forest, and estuarine marsh communities and resources.

2. Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes where possible and encourage management strategies that can emulate natural ecological processes, including fire, flooding and drought, herbivory, and wind/wave action and that can provide critical resources to key fish and wildlife species.

Important ecosystem changes at Cape Romain NWR include alterations to community composition, especially the alteration and reduction of maritime forests, degradation of estuarine marshes and incision of tidal creeks, loss of fresh and brackish wetlands on barrier islands and mainland forest depressions, erosion of beaches and dunes, and loss of tidal flat areas in several coastal sites. The HGM attribute-matrix information in this report helps refine understanding about the abiotic relationships of various communities and identifies the areas where these communities historically occurred. These HGM attributes also help identify the ecological characteristics that must be present for future siting and restoration/management of specific habitats. In many cases, the physical location and surface of a site dictates the appropriate community that should be protected and encouraged (e.g., tidal flats, beaches, and dunes). In other areas, past land changes have destroyed or highly degraded native communities so that they will be difficult to restore (e.g., freshwater wetlands on barrier islands). As a general goal of maintaining as near a natural community mix and distribution as possible, the CCP and this report offer guidance about the ecological attributes that must be present to restore and maintain specific habitats and locations. Specific recommendations for the restoration and management of the major community types at Cape Romain NWR are provided in the next section of this report.

Fortunately, much of the basic community distribution at Cape Romain NWR is not highly altered from a natural state. However, the systemic changes that have occurred to the system, or that may occur in the future, will require active management of at least some habitats and areas on the refuge. Future management strategies should have a solid ecological foundation and be conducted in an adaptive management framework where monitoring and evaluation can provide information to adjust and improve techniques, methods, and strategies. As a core premise, management of major disturbance events that can be controlled should seek to emulate timing, duration, extent, intensity, and dynamics of natural processes including fire, herbivory, flooding and drying regimes, tidal action, and other physical events that can emulate a larger natural occurrence such as sediment scouring and deposition caused by storms, winds, and waves.

With the advent of continued climate change and sea level rise, the coastal water levels and tidally-affected areas at Cape Romain NWR likely will change. The timing, extent, and ultimately effects of this sea level change on the Cape Romain ecosystem are unknown and various projections suggest different scenarios of change. Regardless of timing and extent, however, some changes to the dynamic land-water shore and tide lines undoubtedly will occur. Consequently, the wetland areas now in saline-brackish-fresh states may change and any existing wetland management infrastructure currently in place to manage these conditions may or may not be adequate or suited to the new coastal tidally affected areas. For example, levees and culverts on Bulls Island may become inundated or highly damaged with higher tide surges and levels, the dam infrastructure at Jacks Creek and other impoundments may not be of a height or configuration to create dynamic fresh-brackish habitat in winter, and some inland freshwater depressions may ultimately become brackish or saline as waters rise. Nonetheless, management and development of other sites may be able to replace lost habitats, such as creating potential new wetlands in more inland areas.

SPECIFIC RECOMMENDATIONS

Maintain and restore the physical and hydrological character of the regional South Atlantic coastal environment and ecosystem.

Conservation actions to protect, restore, and manage the regional South Atlantic coastal ecosystem where Cape Romain NWR is located will require attention to many "system-level" factors including imminent or anticipated potential threats, opportunities, and needs. Specific opportunities for USFWS (and refuge staff) involvement to address larger systemic issues are included in the refuge CCP. These recommendations and other important actions suggested by this HGM evaluation include:

1.1 Work to expand the acquisition boundary of Cape Romain NWR with goals of: 1) providing ecological connection between the refuge and the Francis Marion National Forest; 2) creating larger mainland buffers for critical habitats and areas; 3) protecting and enabling restoration of habitat types such as fresh and brackish coastal wetlands that have been highly destroyed or altered; and 4) providing potential areas for replacement of coastal estuarine habitats as sea levels continue to rise.

1.2 Develop long-term strategic plans to protect and replace tidal marsh, tidal flat, and inland wetlands under scenarios of up to 2 m sea level rise over the next 100 years. These plans should be supported by expanded and updated sea level rise modeling efforts that incorporate contemporary information on regional subsidence, marsh accretion, refined LiDAR topographic data, and costs of maintaining or building new protective dikes and other containment structures. After models are used and/or revised, mainland areas within an expanded refuge acquisition boundary should be evaluated for potential to support estuarine marsh, maritime *forest, and freshwater wetlands based on soil, elevation, and hydrology information, such as is provided in Table 5. For example, mainland sites with Rutlege, Megget and Cape Fear soils are potentially suited for freshwater wetland depressions because of their water retention capabilities.*

1.3 Cooperate with the Santee Cooper Power Company and state partners to ensure adequate freshwater and sediment inflows into coastal bays, marshes, and barrier islands (see discussion in the refuge WRIA (Faustini et al. 2013) and other literature about pre-dam sediment yields and water flow (Hockensmith 2004, Paterson et al. 1996, McCarney-Castle et al. 2010). The USFWS should work with appropriate authorities to assure that FERC relicensing of the Santee Cooper Dam includes provision of adequate water and sediment flows to Cape Romain NWR and account for ecological impacts of dam/reservoir management to the coastal ecosystem. The USFWS should support efforts to develop models and estimates of the amount and timing of freshwater flows into regional bays and estuaries that will emulate historical freshwater inflows necessary to sustain estuary, coast, and bay communities. Continue to evaluate potential solutions to restore more historical sediment discharges to the bays.

1.4 Continue to work with the USACE to change dredge deposition sites from onshore to offshore to increase the amount of sand that is transported down the coastline and that could potentially become deposited on barrier islands to offset erosion and loss of barrier islands. Efforts should be made to explore options for use of local dredge material to create and restore wetlands and tidal marshes.

1.5 Cooperate with the EPA, U.S. Coast Guard, and state agencies to prevent, remove, and mitigate hazardous waste, materials, oil spills, and degraded water quality within the region.

1.6 Work with the USACE to ensure that maintenance and new construction on the AIWW does not cause increased coastline erosion, disturbance to critical habitats and resources (e.g., winter foraging sites of waterbirds), deposition of dredge material and spoil in degrading locations and patterns, contamination from hazardous materials, or deposition of material containing soil seed banks of undesirable invasive plant species.

1.7 Work with many partner agencies and groups to monitor and develop strategies for protection, and possible rebuilding, of the barrier island shorelines from excessive erosion, loss of accretion, storm and wave effects, and sea level rise (http://coastalgadnr.org/sites/uploads/crd/images/LivingShorelines/LivingShorelinesAlongtheGeorgiaCoastweb.pdf).

Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes where possible and encourage ecological processes and disturbance events that can emulate natural disturbance events including fire, flooding and drought, herbivory, and wind/wave action and that can provide critical resources to key fish and wildlife species.

An important part of the HGM evaluation is the identification of the natural community types and the evaluation of their current and historic distribution on the refuge within the Carolinian-South Atlantic Biosphere Reserve (http://www.unesco.org/mabdb/br/brdir/directory/biores.asp?code=USA+40&mode=all). This information helps managers understand if the current community types and distributions are highly modified from a former state and helps guide future management strategies that will:

- Protect habitats and locations that are similar to historic areas,
- Enhance habitats that are still present in historic locations but that have altered physical form or processes, and
- Restore habitats that have been converted from a former type to a new type or condition.

The following management options are presented by community/habitat types identified in the HGM report (Table 5, Fig. 16). This historical community distribution information provides “first-order” guidance to determine whether a site/habitat should be protected, enhanced, or restored and if specific management techniques or strategies can be used for the various areas within Cape Romain NWR as it exists today. The following discussion of specific management options for communities expands that provided in the recent CCP and WRIA for the refuge.

Beaches and Sand Dunes/Spits

Beaches and dunes on Cape Romain NWR are primarily located on barrier islands, which while still present in historical locations, have degraded ecosystem processes such as rapid beach erosion because of decreased sediment aggradation and sea level rise. Further, beach and dune areas on Cape Romain NWR seem highly susceptible to continued erosion and loss based on SLAMM models that predict a gradual decline in island area and beach/dune habitats. Long-term solutions to beach and dune erosion and loss are difficult because of predicted climate change scenarios, and ultimately either the islands will become inundated or subject to extreme erosion. Strategies to address climate change and sea level rise are beyond the scope of this HGM evaluation, but a few short-term management actions include:

2.1 *Protect existing beach and dune habitats from development, physical degradation, disturbance, and contamination by prescribing "protective status" limitations to access and use. Certain island areas on Cape Romain NWR are within the Class I Wilderness Area and already received legal protection status. Further, in these areas, precedents for closed seasonal or spatial access periods related to undisturbed nesting periods and areas has occurred and should be continued or expanded based on monitoring of sensitive species and habitat resources.*

2.2 *Control access to, and use of, beaches and dunes from vehicles, aircraft landing, and other human uses including management activities, except for enforcement of protective status and monitoring/evaluation of physical form, species use and survival, and contamination issues. Current vehicle use on beaches and dunes such as ATV traffic should be evaluated to determine potential habitat degradation from erosion following high tides or large spring tide flooding. Take actions to minimize disturbance and apply minimum requirement analysis in the Wilderness Areas (USFWS 2008).*

2.3 *Create "no entry" water buffer zones to minimize disturbance to beach areas, especially those areas that attract and support nesting loggerhead sea turtles, sea birds, piping and Wilson's plovers, shorebirds, American oyster-catcher, and sea beach amaranth.*

2.4 *Remove and control invasive plants and animals on beach/dune areas. Work with partners (Port Authority, etc.) to prevent introduction/infestation of new and emerging threats. Monitor for newly established invasive species to better target Early Detection/Rapid Response (EDRR) efforts.*

2.5 *Evaluate methods to restore native plant communities on beach/dune areas, especially for sea beach amaranth.*

2.6 *Conduct necessary beach cleanup activities and prevent accumulation of debris and hazardous materials as possible.*

2.7 *Continue to evaluate potential methods and opportunities to protect islands and beach/dune habitats from further erosion and to re-nourish and rebuild beaches within constraints of Wilderness Area designation. Past attempts to rebuild beaches within the refuge with sand placement and movement on Cape and Bulls Islands had mixed success and some negative impacts (e.g., nest entombment, USFWS refuge annual narratives), but the high rates of coastal beach erosion dictates that efforts to slow erosion or actually rebuild beaches is desirable. Pilot projects are underway to evaluate the construction of off-shore breakwater structures made with natural materials (shells). In other Atlantic Coast areas, sand and other dredge material has been placed either directly on island fringes or immediately offshore to help break wave action and to potentially supply sediment material to island beaches. If erosion-sediment deposition projects are initiated at Cape Romain NWR, they should be carefully designed and evaluated to determine direct and indirect effects on physical and biological concerns (e.g., http://coastalgadnr.org/sites/uploads/crd/images/LivingShorelines/Living-shorelinesAlongthe GeorgiaCoastweb.pdg).*

2.8 *Pursue management suggestions in recommendations 1.6 and 1.7 about spoil dredge and adding to islands for rebuilding or moving offshore to help provide sediment supply.*

Maritime Forest

Maritime forest historically was, and remains, a dominant community on ridge-and-swale surfaces on barrier islands and the mainland edge of Cape Romain NWR that extends inland to the Francis Marion National Forest. The maritime forest community on mainland areas has been fragmented, cleared and converted to other uses such as agriculture and commercial/residential development. Historically, both mainland and Island maritime forests had embedded swales that contained small freshwater wetland depressions. In mainland areas, management of maritime forest should seek to restore forest to areas that have been cleared or degraded and to actively manage remnant stands for native composition and disturbance regimes.

The island maritime forest on Bulls Island, while still present in much of its historical distribution, has been altered by hurricanes and invasion by invasive species including Chinese tallow. Island maritime forest was dominated by more live oak and non-pine species and had infrequent fire. The unique "non-fire driven" Island maritime forest habitat should be maintained and enhanced/restored to a more natural community assemblage. On Bulls Island, a primary management need is to remove invasive Chinese tallow and seek reestablishment of native species. Because the native species composition of Bulls Island maritime forests was not "fire dependent," the use of prescribed fire in this forest is not recommended because it likely would encourage "fire climax" species such as pine and tallow, which are not desired. Removal of Chinese tallow will require persistent efforts that may include several techniques. .

Specific management actions for maritime forest habitat include:

3.1 *Protect existing maritime forest from conversion to other uses and habitats by restricting development, disturbance, fragmentation, and unnatural alteration.*

3.2 *Generally exclude prescribed fire to manage maritime forests, except in potential cases of accumulation of heavy fuel loads from downed woody debris, where highly managed prescribed fire can be used to prevent a catastrophic wildfire event. Directly plant native oak and magnolia species where they have been destroyed or degraded, such as in sites heavily impacted by Hurricane Hugo. Ultimately, management should seek a more closed canopy condition, which appears to have been the more natural climax or mature ecological condition or state.*

3.3 *Long-term monitoring and research of the Bulls Island maritime forest is needed to determine community state and whether some active management may be needed in the future.*

3.4 *Control invasive plants and animals in all forested areas and seek to remove, prevent, and control Chinese tallow from Bulls Island to allow regeneration and restoration of native forest species. Removal of tallow will require physical removal along with treatment by chemical or mechanical means.*

Upland Forest

Maritime forests transitioned to higher elevation upland forest communities on the South Carolina mainland. These upland areas contained extensive stands of pine and associated upland tree species that were heavily harvested and cleared in the late 1800s and early 1900s. While Cape Romain NWR contains relatively little upland forest, fortunately, the large area of upland forest near Cape Romain NWR has been protected in the Francis Marion National Forest. This national forest land represents an excellent opportunity for ecosystem connectivity with the refuge and future restoration and management of upland forests for both properties should be coordinated and complimentary. Specific recommendations for upland forest conservation as part of Cape Romaine NWR includes:

4.1 *Protect existing upland forests from conversion to other uses and habitats by restricting further development, disturbance, fragmentation, and unnatural alternation.*

4.2 *Acquire upland pine forest habitat as part of Cape Romain NWR to connect with Francis Marion National Forest and other conservation lands.*

4.3 *Restore native longleaf pine habitat to appropriate areas in existing forest tracts and in potential restoration sites that could be acquired and converted from non-forested habitat to native upland forest.*

4.4 *Manage mainland upland pine forest with prescribed fire, harvest and timber stand improvement methods partnering with the*

Francis Marion National Forest (see e.g. the history of longleaf pine conversion, restoration, and management in Croker 1987)

Emergent Estuarine Marshes and Adjacent Tidal Flats, Shell Rakes, and Oyster Bars

Emergent estuarine marshes historically (and currently also) covered about 75% of the non-open water area of Cape Romain NWR and provide essential habitats and resources for many species in this ecosystem. Some intentional development and management of these estuarine and tidal flat areas has been conducted on Cape Romain NWR in the past for some areas (e.g., levees and culverts on Bulls and Cape Islands), but management has gradually evolved to allow a more passive, natural daily and seasonal hydro-regime based on tidal entry and exit, such as abandoning infrastructure on Cape Island. The evolution of management to a passive, hands-off, approach was especially facilitated by the designation of most of the estuarine marsh area as a Class I Wilderness Area in 1975. Wilderness Area designation, by law, restricts access, development, and most direct management of this area. Refuge management to date has sought to minimize direct management of marsh, tidal flats, shell rakes, and oyster bars except for actions that protect or reestablish these habitats. Some important management strategies to sustain these important communities include:

5.1 *Protect existing tidal flats, shell rakes, oyster bars, and emergent marshes from fragmentation, erosion, contamination, and unnatural disturbance.*

5.2 *Evaluate mainland and coastal edge sites that could be restored to native estuarine and tidal flat areas to mitigate for loss due to future sea level rise.*

5.3 *Establish and expand permanent vegetation/community monitoring locations in all marsh, tidal flat, shell rake, and oyster bar areas to determine short- and long-term changes in vegetation composition and distribution, sediment and land area loss or aggradation, physical form, incision of tidal creeks, and hydrological regime.*

5.4 *Prevent, control, remove and mitigate hazardous waste, materials, and oil spills to the degree possible. Coordinate Emergency spill response plans with partner agencies, especially EPA and USACE.*

5.5 *Work with partners to model and evaluate mainland and coastal edge sites that may be converted to estuarine and tidal flat areas due to future sea level rise. Refine projections of potential changes in distribution and extent of tidal flats and marshes along with expectations of headwater incision of tidal creeks under various sea level rise scenarios and develop strategic plans for establishment and protection of new tidal marsh areas in areas more inland to current tidal areas.*

5.6 *Partner with the state of South Carolina to evaluate historical and current oyster beds to determine their status, integration with estuarine marshes, and potential needs for restoration. http://www.scseagrant.org/Content/?cid=626*

5.7 *Conduct studies of the current distribution of shell rakes on Cape Romain NWR and work with the USACE to protect and restore shell rake areas related to navigation and ecological considerations.*

5.8 *Evaluate the use and extent of water buffer zones (i.e., restricted water traffic) to minimize disturbance to nesting wading birds, wood storks, and marsh birds.*

5.9 *Similar to barrier island management (see above) evaluate the placement of shell barriers in bay areas adjacent to tidal marshes and flats to reduce wind/wave action and erosion of marsh/flat sediments. The locations for potential shell barriers should be carefully evaluated and designed so as to not reduce water movement and connectivity between bay and marsh areas and to not deter sediment deposition from near-shore currents.*

Interior Freshwater and Brackish Wetlands

A few small fresh and brackish wetland depressions historically were present in small swales on the barrier islands at Cape Romain NWR, and were more numerous and widespread in depressions within mainland forest areas. These wetlands provided important freshwater resources used by many species and added heterogeneity to the ecosystem. In recognition of the value of these wetlands, Cape Romain NWR sought to develop and manage more sites for fresh and brackish water regimes, beginning with the construction of the Jacks Creek dike across the upper end of Bulls Island in the early 1940s. The construction of the dike across Jacks Creek (and also upper tidal creek areas now in Moccasin Pond, New Pond, and Pools 1-3) converted a former tidal marsh/creek area into a protected wetland impoundment with fresher water regimes. This transformation, while enabling more fresh and brackish water habitat, has come with the cost and risk of continued exterior levee and water-control infrastructure damage and repair. Subsequent impoundment construction developments at Big, House, and the Summerhouse ponds also enabled management of fresher water regimes and currently 10 fresh/brackish impoundments are present and maintained on Cape Romain NWR, all of which are on Bulls Island. Sea-level rise and loss of sediment that rebuilds barrier island beaches and provides land buffers to inland freshwater wetlands threatens the long-term viability of existing wetland impoundments. The supply of freshwater to existing impoundments is inconsistent among years because of variable interannual rainfall, but this dynamic is part of the long-term sustaining wet vs. dry hydrological regime of the system. Improving the reliability of freshwater for management efforts would be beneficial so long as water management regimes emulate natural seasonal and interannual regimes. Efforts to provide annually consistent flooding of the wetland impoundments generally are not desirable because it could promote even more unnatural water management and reduce long-term wetland productivity. Natural seasonal hydrological patterns include pulses of freshwater inputs in spring following increased rainfall, while long-term dynamics reflect alternating patterns of wet vs. dry year precipitation amounts.

Certain island morphology data estimates suggest that the front beach on Bulls Island is losing about 25 linear feet per year. The dilemma for refuge managers is how to maintain wetland impoundments in the short-term knowing that long-term loss of these habitats is likely. With the likely sea-level rise scenarios projected for the region, future provision of freshwater wetland depressions may be best suited for, and encouraged on, mainland areas where swales with Meggett, Cape Fear, and Rutlege soils are present. Future efforts to manage and restore freshwater wetlands include:

6.1 *Protect the physical and hydrological integrity of small wetland depressions in swales (Dawhoo soils) on Bulls Island and other potential mainland refuge expansion where (e.g. Rutlege, Meggett, and Cape Fear soil signatures are present), by preventing or removing land surface alterations, restoring natural movement and flow pathways of water to the depressions, and providing native cover buffers to the site.*

6,2 *Maintain existing levees, culverts, and water-control structures on Bulls Island where desired, but manage this infrastructure to allow natural ebb-and-flow of tidal entry and exit to the degree possible.*

6.3 *In the short-term, continue to evaluate ways to maintain at least some fresh to brackish wetland habitats on Bulls Island.*

6.4 *In the long-term, restore freshwater and brackish wetland impoundments on Bull Island to tidally influenced emergent estuarine marsh habitat, given future sea level rise scenarios. Given that most impoundments on Bulls Island actually were created by converting natural tidal flats to artificial diked impoundments, the gradual conversion of the impoundments back to tidally influenced flats and emergent estuarine marsh represents a form of marsh restoration that should be considered under future sea level rise scenarios.*

6.5 *Protect and restore freshwater wetlands in forest swale locations along the coast through expansion of Cape Romain NWR, especially by protecting the physical form and hydrological functions of these sites. Likely, conservation and restoration of mainland freshwater wetlands can "replace" freshwater habitat on barrier islands lost as a result of future sea level rise.*

6.6 *Manage and modify existing water-management infrastructure on Bulls Island to emulate more natural seasonal and interannual dynamics of freshwater entry, storage, and release.*

6.7 *Control woody vegetation expansion into freshwater wetlands using chemical and mechanical treatments as needed.*

6.8 *Prevent future introduction and establishment of non-native species, control occurrence and expansion of invasive and exotic plant and animal species, and monitor for early detection and rapid response of new non-native species introductions.*

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RESEARCH, MONITORING AND EVALUATION

The current understanding of the Cape Romain NWR ecosystem has been greatly enhanced by documentation of system attributes and management actions (such as in the past annual narratives of the refuge), monitoring of coastline erosion, evaluation of the success of certain management activities (such as control of Chinese tallow), and species-specific studies of vegetation and animal communities (for example the monitoring efforts for loggerhead sea turtles, wood storks, American oystercatchers, and waterfowl). Future management of Cape Romain NWR should incorporate key monitoring studies and direct research as needed (Paveglio and Taylor 2010). Monitoring will be determined primarily by refuge objectives, but some measures should be collected that indicate how factors related to ecosystem structure and function are changing, regardless of whether the restoration and management options identified in this report are undertaken. Ultimately, the success in sustaining communities and ecosystem functions at Cape Romain NWR will depend on how well the physical integrity and hydrological processes within the refuge can be protected, restored, and emulated by management actions relative to sea level rise and the loss of coastal barrier island habitats. Coastal processes need to be evaluated at the appropriate spatial and temporal scales. Therefore, monitoring and evaluation of the management strategies employed at Cape Romain NWR must be conducted long enough to account for the spatial and temporal rate of change for the different abiotic and biotic characteristics that are altered (Michener and Haeuber 1998).

Within the context of climate change, rising sea level and other associated changes add a level of uncertainty for long-term planning and future management actions for Cape Romain NWR. Whatever future management actions occur on Cape Romain NWR, activities should be done in an adaptive management framework where: 1) predictions about community response (e.g., decreased Chinese tallow) relative to specific management actions (e.g., chemical treatments) in specific locations or communities and 2) follow-up monitoring is conducted to evaluate ecosystem responses to the action. Specific information and monitoring needs for Cape Romain NWR related to the hydrogeomorphic information evaluated in this report and also identified in the refuge WRIA are provided below:

- ***Obtain complete LiDAR topography data for the refuge.***

LiDAR data for the Cape Romain NWR region were acquired by the South Carolina LiDAR Consortium in 2009, but the processing of this data currently only allows a confirmed accuracy at a two-foot interval. This scale of processing does not allow elevations on the refuge to be mapped at a level (< one foot) that would define the relatively modest ridges, swales, and depressions that exist in specific areas and soil types. If the LiDAR data can be processed to a finer resolution, the HGM vegetation maps produced for this report could be refined to identify specific areas that were, or that could be restored to, shallow freshwater depressions on the mainland and Bulls Island. Further, refined LiDAR maps could be used as a template to stratify future vegetation inventories and maps (see below). These LiDAR maps could also help refine models of sea level rise and potential effects of beach and marsh erosion and inundation.

- ***Evaluate methods and efficacy of controlling invasive species.***

The challenges of controlling and hopefully removing damaging invasive species at Cape Romain NWR will require continued experimentation and vigilance to treatment efficacy. The maritime forest on Bulls Island and other refuge and mainland areas was heavily damaged by Hurricane Hugo in September 1989, which ultimately led to an expanded invasion of Chinese tallow (Conner et al. 2005). Past efforts to control Chinese tallow have had some success, but simply removing existing plants will not be sufficient in the long term to remove the constant threat of expansion and reestablishment of the species. Ultimately, a combination of treatment plus suppression of fire, coupled with efforts to restore more closed canopies of native maritime forest tree species will be needed. Similarly, control of wetland invasive species such as Phragmites will require multiple treatment methods along with restoring basic natural hydrological and disturbance regimes to wetlands. .

- ***Conduct long-term monitoring of water quality, tide and bay regimes, and sea level rise.***

In many ways, the lifeblood of the Cape Romain NWR ecosystem is the highly connected tidal environment of the bays and coastlines behind the barrier islands. Any additional future changes in inputs of freshwater and suspended sediments from inland rivers and creeks, incision of tidal creeks, erosion and change in coast lines and barrier beaches/dunes, contamination and deposition of hazardous and other harmful materials, salinity of bays and estuaries, and wind/wave action potentially could have deleterious effects on the Cape Romain ecosystem. Many long-term bay and coast monitoring efforts are ongoing and they should be continued. Other efforts to model impacts of sea level rise also have occurred and should be refined as more information becomes available. Site-specific monitoring also is needed to document area and ecological condition changes for important areas, such as critical beach areas used by nesting sea turtles and birds, oyster beds, shell ridges, and others.

- ***Evaluate and Monitor long-term changes in vegetation and animal communities.***

The availability of historic vegetation information coupled with regularly documenting changes in general and specific vegetation communities is extremely important to understand the long-term changes and management effects on Cape Romain NWR. Also, regular monitoring of trust resources (e.g. species level monitoring, population level monitoring) helps define the capability of the Cape Romain NWR ecosystem to supply key resources to, and meet annual cycle requirements of animals that use the refuge and regional area. Important survey/ monitoring needs, as identified through various refuge documents include:

- Conduct detailed mapping of the cover, density, and diversity of vegetation species, including invasive species, on all refuge units over time in relation to management strategies.
- Document changes in extent of different wetland and upland habitats as hydrologic changes occur in relation to timing, duration, periodicity, and source of water resources utilized.
- Monitor occurrence, timing, and habitat use of key migratory and breeding species, including sea turtles, Neotropical songbirds, secretive marsh birds, waterfowl, sea birds, and colonial waterbirds.
- Evaluate the use and recurrence of fire in grassland, woodland, and tidal marsh areas in relation to control of invasive weeds and promotion of native vegetation cover and diversity.
- Evaluate vegetation response to managed disturbance strategies such as fire, grazing, mowing, flooding/drying, and chemical treatment.
- Document the occurrence, distribution, and abundance of invertebrates in relation to different hydrologic regimes, wetland types, and management strategies.

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APPENDIX

Appendix A. Historical vegetation community/habitat types identified on Cape Romain NWR during the HGM process in relation to NatureServe's International Terrestrial Ecological Systems Classification. NatureServe's terrestrial ecological system classification defines groups of plant communities that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients (Comer et al 2003; Comer and Schulz 2007).

Community/Habitat Type	Ecological System	Ecological System Code
Beach/Sand Dune	Southern Atlantic Coastal Plain Dune and Maritime Grassland	CES203.273
Beach/Sand Dune	Southern Atlantic Coastal Plain Sea Island Beach	CES203.383
Tidal Flat	Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh	CES203.270
Emergent Estuarine Marsh	Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh	CES203.270
Maritime Forest	Central Atlantic Coastal Plain Maritime Forest	CES203.261
Upland Pine Forest	Southern Atlantic Coastal Plain Wet Pine Savanna and Flatwoods	CES203.536
Upland Pine Forest	Atlantic Coastal Plain Upland Longleaf Pine Woodland	CES203.281
Freshwater Wetland Depressions	Southeastern Coastal Plain Interdunal Wetland	CES203.258